UNSW CANBERRA | Australia's Global University

2017 Defence-Related Research (DRR)

OUTCOMES REPORT

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INTRODUCTION

UNSW Canberra is the only national academic institution with an integrated defence focus, excelling in defence-related security and engineering research. UNSW was ranked 45th in the 2018 QS World University rankings and 85th in the 2018 Times Higher Education World University Rankings.

The University is acutely aware that undertaking top-quality research is imperative to providing the best possible education to the Australian Defence Force.

The Defence-related Research Grant Scheme was established to provide seed funding for academic staff to pursue defence-related research and to further promote research collaboration between UNSW Canberra and Defence.

The outcomes of all projects that have been funded since the introduction of this scheme have been summarised in the respective Outcomes Reports.

Applications are assessed for investigator(s) track record and project quality by the Faculty Research Grants Committee, while the relevance to Defence is evaluated by the representatives of the Defence-related Research Advisory Committee of the three services.

The membership of the Defence-related Research Advisory Committee (DRRAC) comprises equal representation from UNSW Canberra and the Australian Defence Force.

Total funding of $100,000 was allocated to six projects across the School of Engineering and Information Technology and the School of Physical, Environmental and Mathematical Sciences. With the departure of Dr Robin Robertson from the University in April 2017, only five projects proceeded. This report encapsulates the highlights and achievements of the research projects funded under this scheme in 2017.

PROJECT SUMMARIES

LIFELONG LEARNING FOR TRUSTED ROTARY WING UNMANNED AERIAL SYSTEMS

Associate Professor Matt Garratt

Inspired by the way humans learn, this proposal aimed to develop fuzzy evolutionary systems (FES) for robust and adaptive control of multi-rotor drones. It developed a new adaptive control system that quickly changes its parameters, suitable for real time implementation with limited computational resources. This research contributes to the capability of FES to learn to support real time autonomous control systems from scratch. This enhances the technical applicability of FES to real autonomous systems such as unmanned aerial vehicles (UAVs). It also advances the theory of FES.

This project aimed to develop an FES algorithm that could:

a. come up with both the parameters AND the structure of an FES used for system identification and control of an autonomous system;
b. learn about the system as it gets data from the sensors, actuators and commands without over-fitting;
c. learn to control the system by developing fuzzy rules and refining the rule base, as it evolves, keeping the rule-base simple; and
d. adapt quickly for online implementation on different autonomous systems.

This project was assisted by funding from Defence Science and Technology Group (DST), which paid for engagement of two HDR students in the work ($5k per student) and contributed RA salary through a DST Competitive Evaluation Research Agreement (CERA) project. This project led to a new research agreement with DST in the area of adaptive flight control of flapping-wing micro air vehicles (MAVs).

Fuzzy inference system can be regarded as a process of formulating or mapping input to output variables whose truth values are real numbers between 0 and 1 as opposed to Boolean logic. Under the umbrella of fuzzy systems, TS fuzzy models have multiple advantages due to their capability to deal with non-linearity and uncertainty. The system is also very suitable for numerical computation and is well-suited to mathematical analysis.

Outcomes

We have demonstrated the performance of the evolutionary TS fuzzy system to facilitate learning-from-scratch in aerial robotics, mimicking the way humans learn. It is apparent that the closed loop control systems are able to perform online self-learning, eliminating the demand of having prior knowledge of the fuzzy systems since there was no training (online, nor offline) performed.

Compared to the conventional mathematical-based control systems, the ETS controllers are considered more practical in the absence of the requirements of having complex mathematical models, which may not always be available in practice. Another advantage of the system is its flexibility to learn the dynamics of the plant, to track its parameter variations, and to adjust it whenever required. The optimisation technique is very suitable for non-differentiable, complex, and noisy system.

With respect to the performance of the conventional PID controller, we have shown that the steady state error of our fuzzy autopilot is twice lower than the tracking error of the PID controller, despite bigger overshoot in the transient period since at that time the controller is still in the process of acquiring more knowledge about the dynamics of the system.

Also, the acquired fuzzy models are relatively simple, since the total number of membership functions is only between three to four for all control loops. This is clearly advantageous for real-time implementation, especially for small drones, where the systems are often faced by limited computational power. The practical usefulness of the proposed evolutionary control system is improved by the benefits of the TS fuzzy systems, which are also more intuitive compared to traditional control approaches. This also improves its practical usefulness due to its suitability for the average drone operators.

We believe that in the future the concept of evolutionary fuzzy systems will play more and more important significant roles, especially for challenging applications such as in aerial robotics.

Publications generated from this funding

F. Santoso, M. Garratt, S. Anavatti, O. Hassanein, *Entropy Fuzzy System Identification for the Dynamics of a Flapping Wing MAV*, IEEE World Congress on Computational Intelligence (WCCI) in FUZZ-IEEE Section, Rio de Janeiro, Brazil, July 2018.

F. Santoso; M. A. Garratt; S. G. Anavatti, *A Self-Learning TS-Fuzzy System Based on the C-Means Clustering Technique for Controlling the Altitude of a Hexacopter Unmanned Aerial Vehicle*," International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation, Indonesia, October 2017, IEEE.

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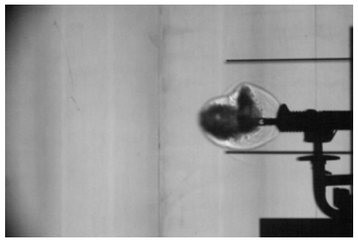
OPTICAL INVESTIGATION OF THE CHARACTERISTICS OF MUZZLE PLUMES FROM SMALL ARMS

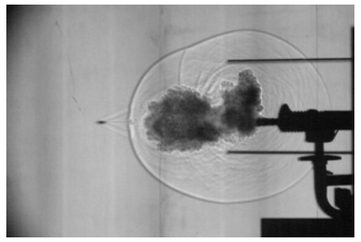
Associate Professor Harald Kleine

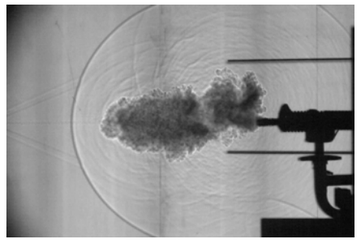
The aim of this project was to build a prototype system for the visualisation and tracking of the motion of a muzzle plume, such as the ones generated by small arms firing in a multidirectional firing range. The plume was to be filmed simultaneously from two sides, which allows one to measure its motion in space. This enables one to assess quickly the effectiveness of ventilation systems installed in the vicinity of the plume and to observe how modifications of an existing ventilation system affect the motion of the plume and hence the removal of pollutants contained in it.

Outcomes

- designed, built and tested a prototype large-scale visualisation system for the detection of gaseous plumes: this system showed that it was feasible to develop a rugged yet sensitive system that can be used indoors and outdoors to visualise flows with density differences;
- based on the success of the prototype system, oversaw the design of a large-scale setup to be used in the ballistic range;
- once the large-scale setup had been manufactured, conducted a first set of tests in the 360-degree ballistic range of SAS in Campbell Bks., Perth, in May 2018;
- these tests proved that the designed system will provide the required data for the assessment of the efficiency of currently installed ventilation systems in the ballistic range;
- both systems met and exceeded the expected performance level in terms of light efficiency, sensitivity and ability to detect the gaseous plumes
- in the large-scale tests, cameras provided by Defence were used. These cameras were shown to have a too low frame rate;
- a second test series, in which high-speed cameras were used, was conducted in Perth in July 2018 – these tests were expected to provide the first actual measurements of plume movements.







The project met all aims that were set in the application. A large-scale two-view visualisation system as indicated in the application was designed, built and tested. These tests were conducted at Defence's multidirectional firing range in Campbell Bks., Perth. As indicated in the application, Defence covered the costs of airfare and accommodation of the CI for these tests. While the tests were a successful proof of concept on full scale, they also revealed that the investigated process was considerably faster than expected. As a result, the images obtained with the cameras provided by Defence yielded a time averaged image of the rifle plumes, which are not entirely suitable for a quantitative evaluation. It was therefore decided to repeat these tests but this time with high-speed cameras, in order to more adequately capture the details of the plume. This second set of tests occured in July in the same test facility. Defence covered all expenses related to transport and accommodation.

As indicated above, the rate at which the plume formed and expanded was unexpectedly high. A literature search conducted at the beginning of the study had not revealed any openly available systematic studies of this process so that data from open shock tube tests were used as reference. The ballistic tests in Perth showed that the plume expansion speeds achieved in the shock tube experiments were considerably lower than those in the rifle tests. This issue was addressed in the next set of tests by using more adequate camera equipment.

Once the system has been shown to provide quantitative data of the plume development, the next phase will start, in which a systematic investigation of the efficiency of the ventilation system installed in Defence's multidirectional firing range. This will likely happen within the framework of a research contract with Defence.

Prior to the aforementioned test series, a smaller (one-view) prototype system was designed, built and tested at UNSW Canberra. Different screen materials, light sources and optical arrangements were evaluated. One main result of these tests was that only a single screen material is suitable for a light-efficient capture of the process. Defence was able to source and purchase this material in the larger quantity needed for the large-scale system and kindly donated about eight square metres to the CI. The prototype system will continue to be used for the implementation of setup changes and the continuing quantitative evaluation of operational parameters such as determining the influence of exposure times, light source output or optical components.

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EMBEDDING SHEAR THICKENING FLUIDS IN AUXETIC MATERIALS FOR IMPROVED IMPACT RESISTANCE

Dr Jong-Leng Liow and Dr Juan Pablo Escobedo-Diaz

This project studied the impact reducing capability of auxetic foam impregnated with a light weight shear thickening fluid for the development of light-weight body armour. This composite foam provides active protection, becoming solid-like during high-speed impacts to spread the impact kinetic energy but remains flexible and soft during usage by the user. As the weight of the body armour severely limits the flexibility and endurance of soldiers on the field, the light-weight body armour provides better flexibility and protection for the limbs, as well as extending their operational capabilities.

The project aimed to:

1. **Develop shear thickening fluids that are light weight**

   It was successful in producing a shear thickening fluid with a density of 0.7 g/cc, which is considerably lower than the reference shear thickening fluid material, corn starch in water, which has a density of 1.25 g/cc. Different methods of applying the shear thickening fluid to Kevlar cloth fibre were tested. Testing of its impact resistance in a drop tower showed that the shear thickening fluid enhanced the impact resistance of the Kevlar cloth. A drop extensional viscometer was designed and built to enable the relaxation time and extensional viscosity of the shear thickening fluid to be characterised.

2. **Produce light weight auxetic foam material**

   A light-weight auxetic foam material was produce using a common polyurethane foam used for furniture. The foam exhibited a negative Poisson ratio of around −0.1, which means that when it is compressed, the sides will contract by up to 10% of the amount it is compressed. The foam showed a better resistance to impact during drop tower test.

3. **Embed the shear thickening fluids within the auxetic foam material to enhance its resistance to impact**

   Embedding the shear thickening fluid proved more difficult as it the fluid resisted entry into the pores but also it could flow out of the pores slowly due to gravity over time. Work is still underway to modify the fluid

Publications generated from this funding

Bulley, J. 2017 Shear thickening fluids as body armour. The UNSW Canberra at ADFA Journal of Undergraduate Engineering Research. 10(2) 11 pp.

Howard, J. 2017 Fabrication and impact testing of auxetic material. The UNSW Canberra at ADFA Journal of Undergraduate Engineering Research. 10(2), 11 pp.

Liow, J. L. 2018 A low cost extensional viscometer for small relaxation times. Paper to be submitted to the 21st Australasian Fluid Mechanics Conference, Adelaide, Australia, 10-13 December 2018.

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EXPERIMENTAL MEASUREMENT OF FLUIDIC THRUST VECTORING ON A HYPERSONIC NOZZLE

Professor Andrew Neely and Associate Professor John Young

Hypersonic vehicles require fast response aerodynamic control with sufficient control authority. Existing techniques rely on aerodynamic control surfaces that increase mass and drag and suffer from extreme thermal-structural heating. Fluidic thrust vectoring (FTV) employs the injection of a secondary flow into the nozzle exit flow to steer the exhaust and thus vector the thrust. More efficient scramjet designs may therefore be possible using FTV by reducing or eliminating the need for these aerodynamic control surfaces. This project performed the first wind tunnel measurements of control force produced by an FTV unit fitted to an external expansion hypersonic nozzle.

This short project aimed to:

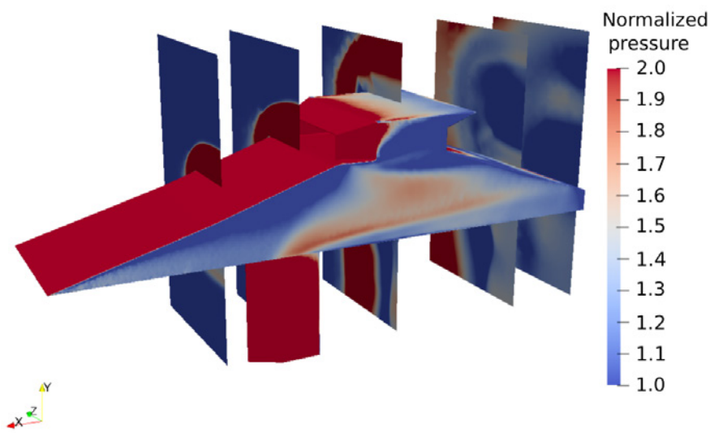
1. Numerically investigate the design of a fluidic thrust vectoring system incorporated into an external expansion scramjet nozzle as a potential means of applying a lateral control force to a vehicle in hypersonic flight without requiring the use of movable aerodynamics surfaces.

   It was successful in achieving this and the computational fluid dynamic (CFD) simulations of these configurations were presented at the International Society of Air Breathing Engines (ISABE) conference in the UK in September 2017.

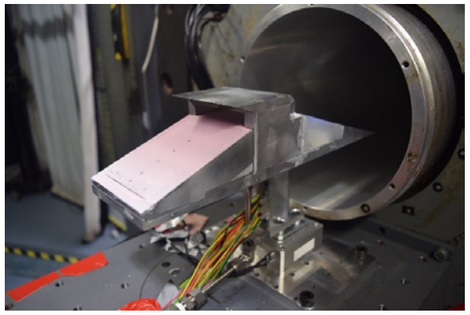
2. Perform the first experimental demonstration of a fluidic thrust vectoring on a scramjet nozzle configuration in a hypersonic cross flow. It was successful in doing this but also highlighted some challenges with the experimental technique, especially in regard to force measurement, that we have since been working to improve on.

   The outcomes of the numerical design and experimental demonstration allowed us to successfully apply to the USAF for EOARD funding for a one-year project through the US Air Force Office of Scientific Research to perform further testing of hypersonic FTV configurations at the larger and higher pressure High Density Tunnel (HDT) facility at the University of Oxford, in collaboration with Oxford researchers. This work is ongoing.

The experiments funded by this work were central to the final part of the PHD work performed by Hilbert Van Pelt and submitted in his thesis in 2018. Hilbert is continuing to publish this work.



We have also used this work, in combination with our AFOSR-funded work on hypersonic control, to recruit an HDR student from DST Edinburgh. Mithun Kahawala has applied to undertake a part time Masters by Research, from S2 2018, to investigate the relative performance of aerodynamic and fluidic control of a generic hypersonic vehicle incorporating a flow path. This project will also help to support his, and his DST group's growing effort in the guidance and control of hypersonic systems.



Publications generated from this funding

Van Pelt H, Neely AJ, Young J, De Baar JHS (2017) A Numerical Study into Hypersonic Fluidic Thrust Vectoring, ISABE-2017-22546.

Van Pelt H, Neely AJ, Young J, McQuellin L, Buttsworth DR (2019) An Experimental Study of Hypersonic Fluidic Thrust Vectoring on an External Expansion Nozzle, in preparation for submission to ISABE2019.

Van Pelt (2018) Shock Vector Control applied to a Converging-Diverging Nozzle and a Hypersonic Vehicle, PhD Thesis (under examination), UNSW Canberra

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GHOST IN THE NETWORK: SCENARIO-DRIVEN, MODEL-BASED AUTOMATED CYBER RED-TEAMING FOR DEFENCE AND MILITARY NETWORKS

Dr Ben Turnbull

There is an ongoing need to understand the impact of a vulnerability on defence computer network systems. Can hackers exploit it? What does this mean to the mission relying on this computer? Which system should we remediate first?

This project continues an existing collaboration to improve cyber situation awareness across networked defence platforms and forms the basis for an ongoing machine learning and artificial intelligence project.

The outcomes of this work are both academic and software-based. The aim is to provide a community around this software to serve as a platform for ongoing research collaboration.

The proof-of-concept software is complete and operational. Its development is ongoing, based on research needs and external engagement.

From a research perspective, this research opportunity has developed a foundational test software system on which to base future research projects. It is the focus of several research papers, outlining software decisions and the theoretical grounding.

This work has sparked external collaboration with:

- Defence Science and Technology Organisation
- The Australian Army
- University of Texas at San Antonio

This research opportunity has provided several opportunities, both theoretical and applied.

It has enabled the researcher to further develop industry connections with a view to furthering research opportunity. It has also assisted in the development of new capability, which is both a foundational platform for future research and also provides a baseline for collaboration, both national and international.

The research underpinning this work is ongoing, and will serve as the basis of future peer-reviewed publications and externally funded grant opportunities.

Publications generated from this funding

2019, Book Chapter, Modeling and Simulation Approaches, D Ormrod, B Turnbull, Cyber Resilience of Systems and Networks, 171-193

2018, Conference Paper, Mission-Centric Automated Cyber Red Teaming, Suneel Randhawa, Benjamin Turnbull, Joseph Yuen and Jonathan Dean, ARES Conference Workshop on Software Assurance, September 2018

2018, Journal Article, Cyber Resilience as an Information Operations Action to Assure the Mission, D Ormrod, B Turnbull, ECCWS 2018 17th European Conference on Cyber Warfare and Security, 343

Others are being written that substantially expand on this work.

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