

Efficient Processing of Towed Array Signals

A/Prof Lal Godara

A towed array system uses a series of hydrophones attached to a cable which is towed behind a surface ship or submarine. Such systems are employed in many applications including detection and tracking of other ships and submarines. By using the 'steering delays' in the reception of a given signal by different elements of the array, signal processing is able to determine the direction of a narrowband signal. This is, however, much more difficult to do with broadband signals. The processing of received broadband signals involves filters of specific frequency response, and updating the filter parameters as the target moves relative to the array. For large bandwidth signals, the current filters require so much computation time that the processing of signals in real time is almost impossible.

The aim of the project was therefore to develop a mathematically more efficient method to update the parameters of the required filters such that the processing may be carried out in real time. Having developed such a method, the researchers, A/Prof Godara and Dr Jahromi, used computer simulation of a test situation involving a target signal and several jamming signals in order to demonstrate that the performance of the proposed method was at least comparable with that of the existing Linear Constrained Method.

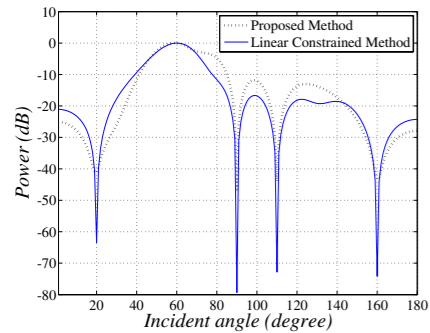


Figure 1. Power pattern of the beamformer using a linear antenna array with number of elements =9, number of taps =125, bandwidth = [0.14-0.30], signal power =1.0, signal direction =60°, number of interfaces =4, each interference power =1.0, interference directions = [20°, 90°, 110°, 160°] and background noise power =0.01. This gives an overall picture of the comparative performance of the two methods.

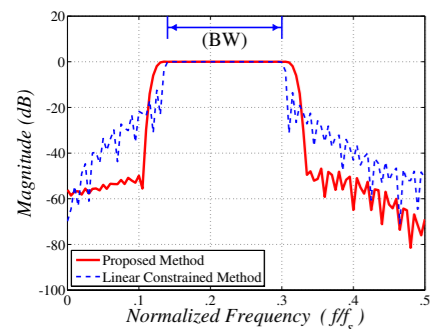


Figure 2. Frequency Response of the beamformer in the look direction, using the same parameters. The proposed method produces an almost ideal response. 'BW' indicates the bandwidth of the desired signal.

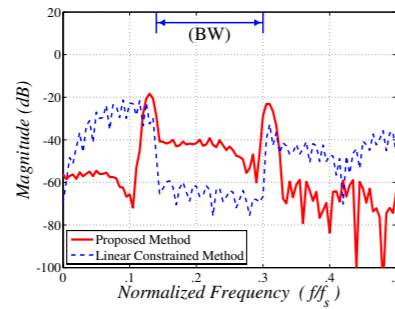


Figure 3. Frequency Response of the beamformer in the direction of 20°, using the same parameters. This is a jamming signal, and the shallower trough in the middle of the red graph shows that the nullification of the unwanted signal is not quite as good for the proposed method. It is still adequate, however: this is a trade-off.

Research in Robust Nonlinear Control Applications to Missile Guidance and Control

Professor Ian Petersen, Dr Valeri Ougrinovski

'Robustness', in the language of control theory, means the ability to cope with uncertainty. In any flight control system, achieving robustness is a challenge which only increases with the speed of the vehicle. A missile which travels at supersonic speed to strike a moving target therefore presents compound challenges, at the same time as the human cost of failure can be very high.

The guidance system must ascertain the missile's location and velocity in three-dimensional space, track the target, and compute a trajectory which will allow the two to converge. The control system must keep the vehicle on that course. Aside from the nonlinearities inherent in aerodynamic situations, a control system must be able to deal with stochastic (unpredictable) events such as gusts of wind and sensor noises.

Linear behaviour involves a response which is proportional to a given input, and although few natural systems behave in this way, control system designers have traditionally had to assume linear behaviour in order to overcome the lack of an adequate nonlinear theory. This approach can work in a given situation if the effect of the non-linearity on the system's behaviour is minimal, but needs to be revisited if the system exhibits significant nonlinear behaviour. A frequently used way of achieving this in missile control systems is effectively to program in a different controller for different stages of the flight trajectory. This so-called 'gain scheduling' enables the control system to allow for predictable parameter variations such as the differing air resistance at differing altitudes and the changing mass of the vehicle as it burns fuel. One of the challenges this project took on is how to do this robustly and to minimize detrimental effects due to frequent controller switching.

The research carried out in this case was not concerned with designing a control system for a specific missile, but rather with the deeper question of how to go about

designing such systems such that they are guaranteed to work. The researchers propose to achieve this through new ways of integrating the evaluation of a system's performance into the design process, using among other techniques, the 'minimax control' technique which they have invented. This method incorporates elements of game theory as well as stochastic optimal control theory.



Sparrow missile under a Phantom aircraft. Photo courtesy of Dr A. Neely

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Defence-related Research Grant Scheme 2006: Outcomes Report

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Introduction

UNSW@ADFA is the only national academic institution with an integrated defence focus, excelling in defence-related security and engineering research and supported by the Defence and Security Applications Research Centre. In 2004, UNSW@ADFA was ranked by Thomson ISI (the international citation agency) in the top 1% in Engineering in the world, based on citations of publications for the period 1998-2002. UNSW@ADFA is acutely aware that undertaking top-quality research is essential to providing the best possible education to the Australian Defence Force. The Defence-related Research Grant Scheme was established in 2006 to provide seed funding to academic staff to pursue defence-related research and to further promote research collaboration between UNSW@ADFA and Defence. Project proposals under this funding scheme are assessed by the Faculty Research Grants Committee which makes recommendations to the ADFA Research Committee for approval. The membership of the ADFA Research Committee comprises equal representation from UNSW@ADFA and the Australian Defence Force. This report encapsulates the highlights and achievements of the research projects funded under this scheme in 2006.

Outcomes

A total funding of \$100,000 was allocated to seven projects, involving four of the five schools: Aerospace, Civil and Mechanical Engineering; Business; Information Technology and Electrical Engineering; and Physical, Environmental and Mathematical Sciences. Eleven journal and conference papers have already been published from this research, with four more in preparation. In addition to the 14 chief investigators, the projects involved two research associates, five research assistants, a PhD student and an Honours student.

The projects, which are summarized below, demonstrate the breadth of subject matter which is relevant to Defence, and draw on theoretical frameworks from economics through psychology to chemistry and electrical engineering. They also demonstrate the fruitfulness of collaborative endeavour: through examining questions of direct usefulness to Defence, several interesting intellectual pathways have been opened up. Both Dr Wallace's project on explosives and A/Prof Frater's work on underwater acoustic channels

have yielded surprise results. Aside from the direct involvement of an Honours and a PhD student, the link between research and teaching, which is central to any university, is drawn even tighter with Ms Burdekin's project, which takes as its research subject the attitudes and behaviours of the ADFA undergraduate student body. This project and A/Prof Markowski's survey of small arms and light weapons in the Pacific region demonstrate the importance of social sciences research to defence operations. Dr Gnanendran's work on airstrips, which has generated interest in the Queensland Main Roads Department, illustrates how research in a defence context may have immediate relevance to a civilian context; this is likely to be true also of other projects such as those involving signal processing. Finally, the project on missile guidance and control systems is a fine example of how the solution of practical defence problems can involve very complex and fundamental theoretical work.



Project Summaries

Electrochemical Remediation Studies of Nitrotriazolone, a New Insensitive Explosive

Dr Lynne Wallace, A/Prof Clifford Woodward



An explosive is a chemical compound which can break down rapidly, producing in the process gas and heat. The expansion of the gas provides the kinetic energy of the explosion. Generally speaking, the more powerful an explosive, the more "sensitive" it is, that is, the more prone it is to accidental detonation through percussion or heat, etc. Currently, there is renewed interest in developing insensitive munitions (IM) which retain power but have reduced sensitivity.

In addition to power, sensitivity and cost, there is a fourth characteristic by which the value of an explosive increasingly is judged, and that is the environmental impact of its manufacture. Nitrotriazolone (NTO) is a new explosive which is both powerful and relatively insensitive. However, it is also highly soluble in water, and there are question marks over the remediation of waste water from the manufacturing process.

This project investigated the electrolytic decomposition of NTO. Oxidative electrolysis resulted in the expected inorganic species, which is useful enough, but the less commonly-used reductive electrolysis produced, totally unexpectedly, a new compound. The nearly colourless NTO solution first turned green, and then a bright yellow precipitate formed (see illustration). Through a variety of tests, including proton NMR and mass spectroscopy, the researchers succeeded in characterising this brand-new compound, which they have named "Azoxytriazolone", or AZTO. AZTO is likely to have similar explosive properties to NTO, but is highly insoluble, which might make it appropriate for different applications from NTO. Potentially, therefore, this research may have solved a waste problem, and created a useful by-product as well.

A further DRR grant for 2007 is enabling Dr Wallace to continue her work on this new compound.

Risk assessment of unsealed airfield pavements due to aircraft turning

Dr Raja Gnanendran

Defence operations often involve the use of unsealed airfield pavements but these airstrips get easily damaged due to aircraft wheel loading. Pilots have observed that at turning nodes in particular, rutting of the pavement can occur well in advance of expectation and this phenomenon is attributed to the significant horizontal (shear) loading in addition to the vertical loading from the aircraft. Dr Gnanendran studied the deformational behaviour of such pavements under concurrent vertical and horizontal cyclic loading through physical model tests, and developed mathematical models which can predict the permanent deformation of the surface. He was able to prove his hypothesis that it is the combination of shear and vertical loading at the turning nodes which causes the premature pavement failures.

This research also casts light on questions raised by the Queensland Main Roads department (QDMR). The testing equipment (the cyclic loading facility, control software, etc.) used in this research was developed in-house, and funding has been sought from QDMR and the ARC (via a Linkage project) to

upgrade the equipment for testing involving large numbers of load cycles, and to monitor the matric-suction during load cycling. This is expected to allow in-depth study of the

fundamental mechanism of permanent deformation development and to enable the study of fatigue behaviour of cementitious stabilized pavement materials.

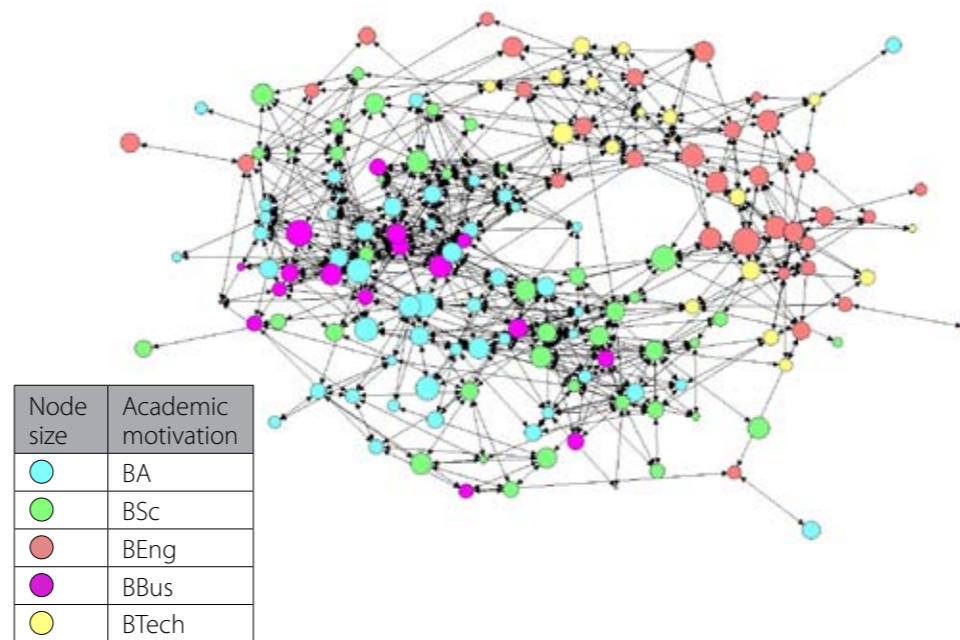


Psychology, influence and selection in dynamic social networks

Ms Sue Burdekin, A/Prof Hussein Abbass, Mr Martin Copeland

Upon arrival at ADFA new cadets undergo many changes in making the transition from civilian to service life. The attitudes acquired by ADFA cadets are important in shaping not only their own careers, but also the future of the ADF. In order to manage changing attitudes towards, for example, academic motivation, military motivation and risk taking, it is first necessary to understand how changes in attitudes come about. The researchers in this project decided to tackle the question in a novel way, one which combines psychological measures with network theory. Through examining social identification and perceptions of influence, they hope to arrive at a better fundamental understanding of how influences operate within social networks.

The work carried out in this project gives a snapshot of the attitudes and social structure of a cohort of ADFA cadets (about 180). The first phase involved a qualitative analysis drawing on interviews carried out by three research assistants. The second phase involved a detailed paper and pencil survey, which was aimed at generating network measures of identified factors. Instead of just the individual measures common in psychological studies, the approach examined dyads, or two-person relationships within the social network.



The diagram pictured above represents the academic contact network, where each node is a cadet, with larger size indicating greater academic motivation, and an arrow connecting two individuals indicating that they cooperate on academic activities. Individuals are located in the network diagram according to a 'spring embedding' algorithm, i.e. nodes are close together if few network links separate them.

The data set thus created is very valuable, and its analysis continues, however the results to date are very promising and confirm the basic premise of the research: that contact through social networks and perceptions of cadet type are important predictors of similarity in attitudes and behaviours. Funding is now being sought for a larger-scale longitudinal study, which will enable the researchers to characterise the dynamics of influence and attitudinal change.

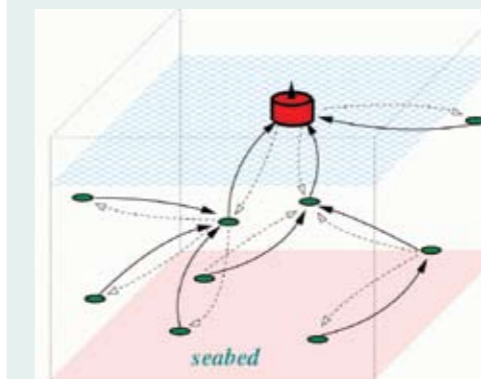
Characterisation of underwater acoustic communications channels in extremely shallow water

A/Prof Michael Frater, Dr Michael Ryan, Dr Robin Dunbar

While there are many important military applications of underwater acoustic communications systems, including the detection and tracking of ships, they have often been seen as the poor cousin of radio-frequency communications. This is partly due to the low data rates achievable in underwater acoustic communications systems, and partly the lack of commercial applications. What work has been carried out tends to concentrate on deep-ocean applications rather than shallow, coastal water.

The first step towards designing underwater acoustic networks must be the characterisation of the acoustic channels: determining signal bandwidth, delay, loss (attenuation), and interference. Having carried this out for shallow water, using Lake Burley Griffin for the experimental validation, the researchers developed a new, high-performance medium-access-control (MAC) protocol that is tolerant of high-delay acoustic channels.

One of the disincentives to undertaking research in this area has been a low theoretical limit to the information carrying capacity of underwater channels. Following the characterisation work, the researchers discovered that a central assumption underpinning this limit is not valid for this application, namely that the behaviour of the channels does not vary according to the signal frequency. This opens the way for denser networks providing more detailed information with a smaller ecological impact. The higher frequency signals attenuate more rapidly and provide a better carrier-to-interference ratio. The MAC protocol allows each node to transmit autonomously without its transmission colliding with that of other nodes. These two things allow nodes to be clustered more densely. And not only does the greater attenuation mean that a smaller area around a network is affected by the signals, but the higher frequencies take the signals out of the hearing range of whales and other marine life.



Real Weapons of Mass Destruction: Proliferation of Small Arms and Light Weapons in Developing Countries

A/Prof Stefan Markowski, Prof Peter Hall

This project focused on the mechanics of proliferation of small arms and light weapons (SALW) in Southeast Asia and the Pacific. There are over 640 million small arms in global circulation (over 1/3rd of them in the USA). Each year, 50,000-100,000 people are killed directly by SALW in 'low-level' conflicts, particularly in poor countries, and at least twice as many die indirectly as 'collateral' victims of SALW-driven conflicts. The former UN General Secretary Kofi Annan has therefore described small arms and light weapons as "weapons of mass destruction in slow motion".



Photo courtesy of the Department of Defence

The research of A/Prof Markowski and Prof Hall to date reveals that over the past decade, numbers of SALW-related casualties in Asia-Pacific have been small. The bulk of 'illicit' arms are concentrated in Southeast Asia, where their main sources of supply are the 'leakages' and theft of weapons from military and police armouries, the (increasingly less important) cross-border smuggling of weapons left over from previous conflicts, battle capture, and craft production in conflict zones. In contrast with the past, there is much less externally driven supply of SALW by superpowers and ideologically motivated expatriates and foreign interests. Urbanisation and the growing economic engagement of Southeast Asia with the rest of the world also act to inhibit armed violence.

Most Pacific nations are insulated from international trade in illicit weapons by their geographic remoteness, small size and low incomes. Craft production is also limited. The researchers speculate that, as there is not much 'business' in the Pacific, there is a risk that high rates of male unemployment may lead in future to SALW-driven violence, and argue that the risk can be mitigated by a combination of increased economic growth and greater opportunities for the islanders to seek jobs in larger regional economies.