The Technical Cooperation Program (TTCP) Collaborative Research for Enhanced Academic-TTCP Engagement (CREATE) call 2016

Multi-modality Sensing and Information Fusion

The US Air Force in partnership with the TTCP nations, is seeking to fund a Research Associate at a US university for a period of twelve months. This call will run in conjunction with four others, similarly constituted in Australia, Canada, and New Zealand.

Background

The Technical Cooperation Program (TTCP) is a five-nation (Australia, Canada, New Zealand, United Kingdom, United States) organization that collaborates in defense scientific and technical information exchange; program harmonization and alignment; and shared research activities for the five nations. See http://www.acq.osd.mil/ttcp/ for more details.

The TTCP Information, Surveillance, Target Acquisition and Reconnaissance (ISTAR) Group, through its constituent nations, is piloting the Collaborative Research for Enabling Academic/TTCP Engagement (CREATE) project. This will enact a coherent international program of basic research across the five nations. The pilot phase will run for twelve months and comprise a level of effort of one Post-Doctoral Research Associate and one PI from each nation addressing an aspect of the call subject.

Introduction

Information has always yielded tactical advantage on the battlefield. In the recent past this has largely been derived from 'physics-based' sensors (e.g. radar, electro-optic cameras). Additionally, significant battlefield advantage has been derived from the exploitation of information from 'human-based' sources. Human-based sources are typically less precise, more categorical and have richer content than physics-based sensors and therefore are typically analysed separately from physics based sensors. Established human-based sources are being augmented with new human-based sources of data (for example social media, free text, webpages) and the proliferation of these lead to a large amount of additional information that could potentially be fused with that from physics based sensors. This drives a requirement for automated fusion methods, which can also mitigate the enormous volume of unstructured data which could otherwise overwhelm human analysts. The fusion of human-based and physics-based sources will enhance situation awareness for various tasks, including the following:

- Finding targets
- Discriminating targets
- Reacquiring targets
- Prosecuting targets which are actively trying to deceive or manipulate
- Surveillance of patterns
- Understanding interactions between entities

Examples of physics-based and human-based sources are given in Table 1.

Few mature methods for the fusion of human-based and physics-based sources currently exist. Some new directions include dynamically integrating instrumentation data into executing models of the system under study, and in reverse the model controlling the instrumentation adaptively manage the collection of data (that is adaptively manage collections of multitudes of heterogeneous sensors/controllers – www.1dddas.org). Practical methods of fusing data from disparate sources to enable better situation awareness are crucial.

Proposals are sought for research into novel fusion methods to improve situation awareness. These methods must be able to fuse data sourced from physics-based sensors with human-based sources of information.

Proposals can be made to address any of the challenges listed in this call. Comprehensive coverage of all challenges is not expected.

This call is being released simultaneously in Australia, Canada, New Zealand, UK and USA (the International Partners). The assessment and award process will run in parallel in each nation. Proposals should be from a single entity or a consortium wholly based in one of the nations of the International Partners. Cross-national collaborations will not be funded in this call. However it is expected that there will be significant collaboration between successful performers from different nations after award.

The level of effort and commensurate funding is expected to equate to one person year at Post-doctoral Research Associate level plus an appropriate level of Principal Investigator oversight per funded project.

This call is intended to procure fundamental research at the lowest Technology Readiness Levels (TRL 1). Expected outputs will be of the form of peer-reviewed conference or archival journal papers plus a short summary report. Products, integrated demonstrations and mature technology are outside the scope of this call. Physics-based and human-based sources of data may be available from international partners in order to assist in the demonstration of developed fusion techniques.

Physics-based sources	Human-based sources
Radar	Text in a conversation
Raw video	Analyst's report based on physics-based sensors
IR Imagery	Wikipedia entries
EO/IR fusion	Human-generated report
ES lines of bearing	Facebook posts
Metadata	Twitter tweets

Table 1: Examples of physics-based and human-based sources.

Background: Fusion in a military context

Fusion of physics-based data from sensors e.g. radars, electronic support measures, electro-optical sensors, imagery and videos, refers to the problem of estimating the state of entities by combining the data from (typically) multiple sensors which are associated with those entities. This is usually done in an effort to produce either a better state estimate than could be obtained from any individual source of sensor data or to allow one sensor to cue another.

While the means by which the data are fused may vary from one application to the next, they are always reliant on two key pre-processing steps. The data first need to be registered which refers to transforming them into a common coordinate system or framework and using common units to quantify them. When there are multiple entities present, a decision also needs to be made about which data are associated with which entity. It is only then that the data associated with each entity may be fused to estimate its state, which is often represented as a vector. While the form of a state vector depends on many factors, in defense applications in which the goal is to enhance the situation awareness of the human end user about a battlespace, the state vectors often hold identification, positional, kinematic and classification information about their associated entities, namely, ships, aircraft and trucks, in that battlespace.

In traditional warfare, this was often adequate because the battlespace was remote from civilian environments. However, modern warfare often plays out in contested urban environments in which the adversaries and their capabilities are difficult to distinguish from regular civilians and the natural features of the environment. For that reason it is desirable to establish an *augmented state* to capture attributes suggested by human-based sources of information such as and social media (for example Facebook, Twitter). While this still entails performing registration and association steps before fusion can be achieved, estimating the augmented state introduces a number of issues:

- Data from these human-based sources often take the form of unstructured text instead of numerical quantities. Consequently the techniques for processing the human-based data can be vastly different to the numerical methods which are applied to physics-based sources, and are generally much more demanding.
- Registering all data within a common framework is also challenging because the processing of data from physics-based sources yields an object-oriented representation of entities in the form of estimated state vectors, while the processing of data from human-based sources often yields relations between entities.
- Unlike numerical state estimates which have a clear meaning derived from the model that has been used to generate them, the processing of the human-based data may need to

incorporate a means of endowing the extracted information with semantics that are faithful to the original source.

- Time-aligning physics-based data is relatively straightforward because timestamps for physics-based data are recorded by the sensor, while the timestamps that record when the human-based data are created may not reflect the time associated with the report. For example, a Facebook entry posted today may refer to the past (for example “I caught up with friends yesterday”) or to the future (for example “I am going overseas tomorrow”).

Challenges

In the defense context, algorithm outputs are required in a timely fashion at sufficient accuracy to provide analysts with the information they need to enable effective decisions. Timescales may range from seconds to several hours depending on the time validity of the fusion product. Therefore, it is important that the solutions to the challenges take into account computational cost, convergence rate and robustness. The trade-offs between these measures may depend upon the application, including, but not limited to, detection, tracking, classification, prediction, pattern of life or finding multi-entity relationships.

We expect proposals to address one or two of the following challenges in depth. Multiple proposals addressing a variety of challenges are welcome.

General Method for Fusing Data from any Source

Performing inference on physics-based numerical data has to date used methodologies that are different from those required for performing inference on human-based symbolic data. A general method for fusing data from any source would enable reasoning (for example, abduction, deduction and induction) regarding the augmented state of the set of entities / situation.

The challenge is to formulate a new general theorem for fusing data from any sources to improve reasoning about the entities, and prove rigorously that this works for any data types.

Intersection between the data spaces of physics based sensors and human-based sources

Each information source can be thought of as operating in a multidimensional hypercube that contains the state space of possible information that source can provide. For example some radars may operate in a state space of range/bearing/Doppler/time/target cross section. One of the challenges of fusing physics-based sources with human-based sources is understanding the intersections between the state spaces of the hyper-cubes of each information source. For example it is clear that there is some intersection between the state space of the radar described above and geo/time-tagged photographs of moving vehicles, but the intersection may be low and/or difficult to fully characterise without addition knowledge about the vehicle. The challenge is to develop techniques that allow mapping of one information source’s state space to another while coping with the uncertainty present in each.

Data and information space dimensional mismatch

In this context of fusion of physics-based and human-based sources, the multi-dimensional data space is large. The inherent information space, however, is often much smaller. The mapping from the high dimension data space to the smaller dimension information space is currently very much an art form, with no simple, best, and unique solution. Additionally, this is replete with a plethora of ill-posed inverse problems, demanding regularization. The challenge is to develop methods for determining an appropriate augmented state for the inherent information space.

How to assign uncertainty / probability

Information going into a target knowledge base can come from a wide range of disparate sources. Usually human analysts will read reports and add entities, attributes and links directly into the knowledge base using a data entry interface. But the source information can be inaccurate, uncertain, incomplete, biased, conflicting or ambiguous.

The challenge is to determine how observations with different types of associated uncertainty can be combined:

- So that uncertainty is suitably assigned numerically to evidence and/or prior information
- So that the level of trust in or reliance on a given data source or piece of data is adequately represented

Incorporating the augmented state into current fusion schemes

While there is maturity in fusion schemes for physics-based sources, they do not accommodate human-based sources, or accommodate them only in a limited fashion. Methods for estimating and predicting the relationships between the states of individual objects are required given inputs from both physics-based and human-based sources. The developed methods would allow the incorporation of these new data into extant fusion schemes and so enable state prediction, update, data association, filtering and smoothing. The challenge is to develop methods of estimating and predicting the augmented state of an entity and the relationship between entities, which allow for the incorporation of human-based observations from novel and underexploited data sources.

Fusion level trade space

Fusion from physics-based sources can take place at various levels (for example, the data, feature, object or decision levels) resulting in a trade-off between accuracies and efficiencies. Incorporating human-based sources adds to the complexity of the trade-off. The challenge is to characterize the trade space for the augmented state for fusion at varying levels. This would lead to methods for identifying an appropriate fusion level given a set of physics-based and human-based sources and a desired accuracy or efficiency requirement.

Context

'Context' covers the setting in which the data are collected and the purpose for which the data are exploited. Knowledge of the context in which data is being collected and processed can enhance the tasks of data association, data fusion, the verification of data sources, and the scheduling of resources. Challenges are:

1. To represent contextual information and use it to perform these tasks for physics-based and human-based sources.
2. To understand a changing context and develop fusion algorithms that are robust to it.

Unmatched data rates and latencies

Many physics based sensors operate on relatively short timelines (e.g. seconds to minutes). Many human-based sources build over longer timeframes, are asynchronous, and can refer to the past or future. These unmatched timelines cause problems for traditional fusion approaches. The challenge is to develop methods to accommodate unmatched data rates and latencies which derive from physics-based and human-based sources.

Pattern of life

Analysts are required to produce intelligence products from increasingly large and disparate data sets. As these sources increase and diversify, the job of making sense of them is becoming beyond the abilities of single individuals. Methods of pattern recognition and classification are required that enable a representation of normality (a pattern of life) to be developed from both physics-based and human-based sources of data. These patterns should enable an analyst to readily address specific intelligence questions. It is anticipated that data sets will be very large, diverse and dynamic. Developed methods are required to cope with these aspects and so deliver timely, interpretable results. Classification of behavior, and detection of anomalies, should emerge as a natural consequence of this pattern recognition activity. Because of the size of the data and operator constraints, unsupervised or very lightly-supervised methods are required. **The challenge is to form a pattern of life and detect anomalies using data from both physics-based and human-based sources.**

Sensor/information-source management and control

The term sensor management is widely understood to involve on-line optimization of future observations of sensors to minimise uncertainty / maximise information gain in a resource constrained scenario. Processing of human-based sources is resource constrained in terms of the processing resources required to make sense of the data collected. Therefore similar sensor management principles could apply within these resource constraints to improve the augmented state estimate. This could apply equally in centralised or distributed architectures.

The challenges are:

1. To develop universal sensor management principles that could equally apply to physics-based and human-based sources and show how these could be used for optimization of control, cueing and decision support.
2. To develop techniques for control in a distributed network of sources for the purpose of estimating the augmented state.

Distributed Fusion

The soldier at the tactical edge needs situational awareness to conduct his/her mission. They also act as human-based information sources; their observations contribute to overall situation awareness. Furthermore, many physics-based sensors are operating at the tactical edge. These soldiers and sensors have access to limited computational resources and battery supplies, and are connected to information networks via spurious, latent and low bandwidth links. In addition, not all nodes on the network have equal computational and network resources. For example, there may be nodes with high computational capabilities. Distributed fusion methods provide robustness compared with centralised fusion, but present challenges associated with data reuse, statistical independence and convergence. **The challenge is to develop novel distributed fusion methods to operate over such asymmetric computing and networking resources that accommodate physics-based and human-based sources.**

Proposal Submission and Evaluation

Proposals should be submitted using the submission process indicated in the solicitation located at

https://community.apan.org/wg/afosr/w/researchareas/7661.dynamic-data-driven-applications-systems-dddas/

Please indicate at the top of your submission that the proposal is being submitted to the DDDAS program in response to the TTCP call for "***Multi-modality Sensing and Information Fusion".*** All proposals will be reviewed in accordance with the standard Air Force Office of Scientific Research (AFOSR) evaluation process and proposers will be notified of selection/non-selection decisions upon completion of the peer review. Each Proposal should address one or more challenges outlined in the call but is not expected to address all the challenges in broad areas outlined in the call.

Important Deadlines:

- Proposal Due Date: September 15, 2016
- Anticipated Notification to proposers: November 4, 2016
- Anticipated Contract Award Date: Will be determined contingent on FY 17 budget

Balancing between the challenges will be undertaken across participating nations. The review will aim to maximize the number of challenges in which work is performed to create a balanced portfolio.
Portfolio balancing is designed to encourage mutual reliance across the full multinational program of work. An international panel of subject matter experts having visibility across all proposals will provide national assessors with advice. The national assessor is then able to use this information to fund those proposals which will maximise mutual reliance across international partners.

Assumptions and Dependencies

1. The research should start within two (2) weeks of the award to ensure coordination of the research activities across the international partner nations. The anticipated award date is October 1, 2016 contingent on a federal budget being in place.
2. Each proposal deemed fundable will be subject to the portfolio balancing exercise.

3. The level of funding for the pilot phase is expected to equate to one person year at Research Associate level plus an appropriate level of Principal Investigator oversight and government technical partnering.
4. The output of the project must be original and novel TRL 1-3 research. A test of this novelty and originality is that it is suitable for publication in academic journals and at academic conferences.
5. Output will be unclassified.
6. Proposals shall be limited to the challenges described above.
7. Complete coverage of all topics is not expected. Proposals should aim to address at most one or two of the technical challenges detailed earlier.
8. It is essential that proposals demonstrate applicability to both physics-based and human-based sources.
9. Multiple proposals from the same proposers are welcome.
10. Collaboration with researchers in other nations who are beneficiaries of the associated calls is encouraged.
11. Each proposal shall include a costed travel plan that includes:
    a. Attendance at one international review meeting hosted by one of the international partners, and
    b. Collaboration visits with researchers in other nations, as described in item 9.
    c. Peer review conference attendance and other activities expected of RAs.
12. The TTCP ISTAR TP1 panel is developing an open source Tracking and Fusion Framework for the development and evaluation of fusion algorithms. Successful proposers are expected to interact with this team. Where possible, software outputs should be compatible with the framework.
13. Research outputs will be assessed at the national level and will be accepted using standard quality metrics.
14. Deliverables shall include source code and data (both where applicable) that permit the reproduction of reported results.
15. Research products (including source code) will be shared across international partners.
16. It is not anticipated that there will be any limitations on conducting or reporting this research resulting from export control regulations. Since this is basic research involving mathematical concepts, algorithmic principles and computational challenges, no ITAR restrictions apply. National representatives will assist with ensuring compliance. Proposals which appear to contravene national export control regulations at the national assessment phase will not be submitted to portfolio balancing.
17. [Local IP conditions clause: intend that the research organization owns the IP, but that the governments have use; have already confirmed that TTCP nations have similar conditions]
18. Government subject matter experts from international partners will be involved in periodic project review and research assessment and may provide non-binding technical guidance and feedback during the project.
19. Proposals shall identify the participating researchers. The submission shall be able to demonstrate a suitable level of expertise in the proposed topic.