Decision Support for Robotic and Autonomous Systems

1. Introduction

The rapid advancement of artificial intelligence, due to great expenditures by commercial firms and military research, brings promise to the near-term applications of robotic and autonomous systems (RAS) in the battlefield. To facilitate applications, decision support is required.

The Dynamic Assessment and Optimization (DAO) service is a family of algorithms and procedures with the capability to support multiple tactical missions. DAO provides commanders and staff with the capabilities to analyze and compare courses of action (CoA) during mission planning and execution. Running estimates of future operations also can be addressed.

2. Dynamic Assessment and Optimization Service

The Dynamic Assessment and Optimization (DAO) Service is a decision support system that transitions qualitative data to quantitative models used for performance analysis and optimization. It assists mission planners with the analysis and comparisons of courses of action in near-real time. DAO is platform agnostic: therefore, it can be integrated into many existing and new military systems and environments without disruption and the need for expensive additional equipment. DAO has the capability to assess, prioritize, predict and enhance system performance in response to the dynamics of tactical missions.

The differentiator of DAO is dynamics. It provides results continually and in near rea-time as a tactical mission evolves. The results indicate the status of robotic and autonomous systems (RAS), assist with command and control, and provide running estimates of future events and RAS requirements.

DAO provides, a selection of automation and optimization algorithms.

- Extension of big data with machine learning and optimization
- Robotic and autonomous system analysis
- Intelligence collection and persistent surveillance
- Battlefield management
- Multivariable analysis and prioritization of mission requirements
- Value analysis: Trade-off and what-if analysis
- Predictive analytics
- Course of action analysis and comparisons

3. Dynamic Assessment and Optimization Family Concepts

NBS has conducted studies and analysis for the course of actions of a relay locator and Pseudolite Command and Control (PLC2). Decision support for the launching and targeting of guided munitions is in progress. Other use cases are to be addressed.

3.1 Existing DAO Applications

a) Dynamically Optimized Pseudolite Navigation Support: Pseudolites are radios that provide a GPS-like signal that can be used by military GPS receivers. Fixed, ground, and aerial vehicular pseudolite (PL) transmitters may be available and active during a mission. They are used in order to maximize the GPS Position, Navigation and Timing (PNT) availability and location accuracy provided to tactical PNT users given a potential jamming of GPS signals in a given area of operation. Since the PNT users are constantly on the move and so are potential jammers, the ground and aerial vehicular PL transmitters require tasking to move and transmit in a manner that optimizes their potential utility to the tactical PNT users. DAO algorithms have been developed to assist with PL command and control.

b) Dynamically Optimized Decision Support for Fires: For battlefield fires, trajectories require the dynamic posting of pseudolite catalogs. For selected intervals of flight, pseudolites (PLs) are assigned for a mobile missile's guidance. The missile communications slots necessarily are prioritized relative to ground vehicle assignments. With enough assessment points, the best PLs that will support the entire trajectory are obtained. For one launch, analysis shows that prioritization makes little impact upon receptions for ground users. But as the number of fires per unit time is increased, ground assignments and slot prioritization might impact upon ground vehicle receptions. Terrain and jamming constraints exacerbate the interference.

The DAO paradigm assigns pseudolites and communications slots dynamically as a missile traverses its trajectory. Multiple fires are considered as well as ground requirements. In concert with previously developed deconfliction and constraint routines (PLC2), a fires officer is assisted with pseudolite decision support during the planning and execution phases of a mission.

c) Dynamically Optimized Net-Centric Connectivity: A mobile relay was under test and development by Army-CERDEC. The relay operated within the midst of 20-50 radios and provided a way station for communications between mobile radios. Previous Army analysis (CERDEC) has shown that rather than transmitting messages point-to-point between radios, transmissions to a robotic relay improves communications performance. Decision support algorithms were developed to position the relay optimally such that successful communications probabilities were maximized. New solutions were computed in near real-time as tactical units changed positions.

3.2 DAO Research

a) Dynamically Optimized Munitions Support: The Maneuverable Mine System is a man-portable, remotely controlled and commandable, man-in-the-loop, force protection and area denial munition. The mines change their locations as a deterrent mission progresses and require continuous optimality computations for effective communications and enemy destruction.

b) Dynamically Optimized Sensor Applications and the Fusion of Intelligence and Combat Data: There is a broad range of data available within the military tactical warfare community. Some of the sensors are defined, others are not. The sensors that have been defined have resulted in a significant amount of data available for processing. The data can be of multiple types: image data, network data, voice data, and other types.

Big Data analysis support the reviewing of available data types, extracting relevant objects from data sources, and establishing patterns that contribute to the computations of running estimates and the integration of intelligence and combat information.

Currently a genetic algorithm and predictive analytics combine the information of intelligence data and combat data to assist with an understanding of tactical mission evolutions. Intelligence data is collected prior to and during a mission planning stage. Combat data are collected while a mission progresses.

Given what is known, probabilistic reasoning identifies the quanta of missing information and where to look in order to observe event locations in time and space.

Data fusion translates to the assessment, identification and prediction of tactical events.

c) Multivariable Analysis: Multi-variable analysis is facilitated by the transition of dashboards to a context model and a further transition of the context model to a neural net.

In machine learning, when high-level data abstractions are integrated with non-linear processes, deep learning is engaged. Artificial intelligence (AI) has for several years been in the winter of research. With deep learning and the solutions of complex associations, revitalization has occurred. In the world's top research laboratories and universities, the race is on to invent the ultimate learning machines that find books, movies, jobs, and dates for individuals, manage investments, and discover new drugs. Deep learning has been applied to the defeat of Jeopardy, chess and Go champions. Similarly, an integration of multi-level neural nets and big data assists with a prediction of enemy behavior or the self-organization of autonomous systems.

A context model is derived from dashboards and represents lower level tasks of the dashboards and their interrelationships. The context/ network model is further transitioned to a neural net. Input nodes of a neural net represent the variables of a system. Internal nodes are the learning mechanisms of the net. They are connected to the input nodes and the output nodes. Deep learning with neural nets is instigated when more than one layer of internal nodes is inserted in the network. The output nodes converge to the relative worth of each input variable. Through the novel transformation process, every variable represented in a system is ranked quantitatively with respect to every other variable.

Universities and large enterprises are spending billions of dollars on research and development. The fruits of those labors now can be applied to tactical systems.

d) Optimal PL Locations

Pseudolites are currently hosted on tactical units and consequently their positions are dependent upon where the units are deployed. Because the tactical units are on the move, the optimal assignments of catalogs are uncertain and in a state of flux. Catalogs provide an identification of those PLs assigned to each user.

At some future time, dedicated PL platforms might become a reality. The platforms can take the form of ground or air units. For dedicated platforms, algorithms have been developed to position all PLs such that the number of assigned and useful catalogs is increased. A genetic algorithm is used to address the extremely large number of possibilities of where PLs might be placed. Given that PLs can be located optimally, running estimates will take on an added significance when addressing future operations. Catalogs will not be degenerated because of the mobility of tactical units.

e) Dynamically Optimized Swarms of UAVs: "U.S. and foreign officials are on high alert after a swarm of drones carrying explosives targeted Russian military bases in Syria."

Swarm behavior is defined in military documents as self-organizing behavior among a group of entities that achieve or attempt to achieve a common goal.

Additional definitions of control and behavior are self-organization and semi-autonomy:

> **Self-Organizing Behavior**: Coordinated behavior by a group of entities with a common goal that requires little or no direction from a central authority. This behavior manifests as specific tasks for each individual that can dynamically adjust with changes in the environment
>
> **Semi-Autonomous Behavior**: Behavior of a system (machine) which interacts intelligently with a human user (collaborator) who might command, modify, or override its behavior. Autonomous behavior is framed by user's capabilities and needs.
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> Swarms of drones pose a disconcerting terrorist threat. They can be launched a great distance from a target such as a super bowl stadium. Their impact could kill thousands of spectators.
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> From a military standpoint, swarms can destroy targets nearby or over the horizon. In any case, GPS is required, similar to artillery fires. Pseudolite have a mission as well.
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> A paradigm and decision support algorithms have been developed for the applications of semi-autonomous swarms. Further research is required for self-organization and the use of swarms in a military environment.

f) Running Estimates: Running Estimates (RE) are generated from the approved mission COAs for maneuvers and fires. Each Warfighting COA is used to generate the Warfighting Function RE. An Enemy COA is used to generate the Enemy RE. Each RE is updated as spot reports come in. A future common operating picture (COP) is generated from the RE at a given point in time.

DAO analyzes the CoA at each snapshot in time for the running estimates.

g) CYBER Decision Support: Measurement tools for cyber security are readily available for the continual monitoring of system performance. But in addition, decision makers and their staff require an encompassing decision support environment to effectively manage large-scale information systems and to develop and execute courses of action in response to deleterious events.

DAO produces a response to the results of measurements and the prioritization of those measurements. Measures of intruder performance (MOP) are defined and if they portray danger to systems operations, countermeasures are instigated immediately. Thus, a means is available to compute MOP and to prioritize detections of system intrusion. The foundation of countermeasures implementation is a continual source of measurements and the processing of their importance within a systems context.

h) Dynamic Assessment and Optimization (DAO) Service to provide Decision Support for Robotic and Autonomous Systems (RAS): Integration of robotics and autonomous systems (RAS) into the military consists of three phases: the near-term (2015-2025), mid-term (2025-2035, and far-term (2035-2045). Optimality is a fundamental adjunct to the three phases.

1. Near-Term: Optimal locations promulgated by Mission Command operations orders in consort with military objectives in off-road, cross-country trafficable terrain.

2. Mid-Term: Sense and respond by moving to new locations autonomously in trafficable off-road, cross-country terrain as well as suburban environments.
3. Far-Term: Sense and respond with fully-autonomous action (surveillance, target acquisition, target cueing, target handoff, battle damage assessment, mine-supported force protection, mine clearing, mine trailblazing, mine placement, extended radio connectivity range, extended navigation range, just-in-time logistics).

   DAO applications are expected to assist with reductions in timelines so that many RAS applications become available in the near future.

i) Optimal Supply Distribution: Expeditionary Maneuver Warfare demands effective use of logistics resources in a dynamic and often uncertain environment. New operational concepts, more demanding operating environments and more diverse operational schemes combine to present the logistician with ever more complex decisions. NBS Enterprises (NBS) is able to transition a prototype Decision Support System (DSS) into a fieldable, web-based system that supports Course of Action (COA) analysis and assists with optimum logistics resource allocation at the operational/tactical level, in the face of a dynamic environment. The COA DSS system will allow commanders at various levels to:

1. Define a mission and automatically generate the associated logistics requirements
2. Receive and implement logistics and operational control parameters (e.g. prescribed loads, operating hours, terrain, etc.)
3. Automatically locate the equipment/resources required to fulfill the mission and optimize their selection and collective point of debarkation
4. Merge several optimized courses of action into a single course of action that leverages synergistic relationships
5. Optimize routes and transportation methods
6. Perform interactive contingency analysis in response to “what-if” scenarios
7. React rapidly to changing circumstances to modify resource allocation decisions
8. Generate reports detailing the selected course of action, as well as those courses of action that have been assessed and saved for back up possibilities
9. Retrograde

j) Optimal Fuel Distribution:

An effective strategy for fuel savings is to employ all means of service optimization, which enhances performance and reduces operational costs.

A target is the reduction of flight or ground times through the use of the optimal assignment DAO Service. Other means of fuel cost reductions are proper selection of supplies, selection of carriers and their locations for mission assignments, and minimization of time on station for missions such as surveillance and target localization. For all carrier assignments, numerous variables and constraints are considered and synthesized. Fuel depots are selected, delivery vehicles are identified, and carriers are assigned. For logistics, supplies are loaded and distributed to drop locations. In some cases, multiple locations are visited. For surveillance, sensor suites that maximize mission results are placed aboard aircraft. Further, aircraft are to be maintained, asynchronous failures occur and personnel sometimes are not available. Another issue is command and control; questions exists as to the best means of allocating carriers to missions, routing of deliveries and the response to asynchronous events. DAO enables optimization from supply depot to delivery and in some cases retrograde.