INTELLIGENT MULTI-UNMANNED VEHICLE PLANNER WITH ADAPTIVE COLLABORATIVE/CONTROL TECHNOLOGIES (IMPACT)

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This symposium provides an overview of a research effort that integrated several autonomy advancements into a control station prototype to flexibly team a single human operator with heterogeneous unmanned vehicles. The autonomy related technologies optimize asset allocation, plan vehicle routes, recommend courses of action and provide a distributed support architecture featuring an extensible software framework. This effort also integrated these technologies with novel human-autonomy interfaces that allow operators to effectively manage UxV via high level "play" commands. Evaluation results indicate that the innovative approach supports operator-autonomy teaming for effective management of a dozen simulated vehicles performing base defense tasks.

Agility in tactical decision-making and mission management is a key attribute for enabling teams of heterogeneous unmanned vehicles (UxV) to successfully manage the "fog of war" with its inherently complex, ambiguous, and time-challenging conditions. This agility requires effective operator-autonomy teaming including the achievement of trusted, bi-directional collaboration and the flexible, high-level tasking required for team task sharing and decision superiority. A tri-service team has conducted research focused on instantiating an "Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies" (IMPACT) by combining flexible play calling for task delegation, bi-directional human-autonomy interaction, cooperative control algorithms, intelligent agent reasoning and autonomic technologies to enable command and control of cooperative multi-UxV missions (Figure 1). A command and control operator in IMPACT could task a total of 12 UxV (4 air, 4 ground, and 4 sea surface vehicles) in response to several unexpected events that arose during a base perimeter defense mission. This symposium will provide an overview of four key aspects of IMPACT that AFRL led: operator-autonomy interfaces, intelligent agent architecture, testbed framework and distributed architecture, and human-in-the-loop prototype evaluation.

Figure 1. IMPACT Control Station Prototype.

IMPACT: Interfaces for Operator-Autonomy Teaming

Gloria Calhoun, Heath Ruff, and Elizabeth Frost

IMPACT's displays and controls (Figure 2) feature video game inspired pictorial icons that present information in a concise, integrated manner to facilitate retrieval of the states/goals/progress for multiple systems and support direct perception and manipulation principles. Multi-modal controls (speech, touch, and mouse) augment a "playbook" delegation architecture and enable seamless transition between control states (from manual to fully autonomous). With this adaptable automation scheme, the operator retains authority and decision-making responsibilities that helps avoid "automation surprises" (Calhoun, Ruff, Behymer, & Frost, in press). By supporting a range of interactions, flexible operator-autonomy teamwork enables agility while responding to a dynamic mission environment. At one extreme, the operator can manually control UxV movement or build plays from the ground up, specifying detailed parameters. At the other extreme, the operator can quickly task one or more UxV by only specifying play type and location with an intelligent agent determining all other parameters. For example, when an IMPACT operator calls a play to achieve air surveillance on a building, the intelligent agent recommends a UxV to use (based on estimated time enroute, fuel use, environmental conditions, etc.), a cooperative control algorithm provides the shortest route to get to the building (taking into account no-fly zones, etc.), and an autonomics framework monitors the play's ongoing status (e.g., alerting if the UxV won't arrive at the building on time). IMPACT's play calling interfaces also facilitate operator-agent communication on mission details key to optimize play parameters (e.g., target size and current visibility) as well as supporting operator/autonomy shared awareness (e.g., illustrated by a display showing the tradeoffs of multiple agent-generated courses of actions (COAs) across mission parameters). Play progress is depicted in a matrix display reflecting autonomics monitoring and a tabular interface aids play management (e.g., allocation of assets across plays). Additional detail on all the play-related interfaces is available (Calhoun, Ruff, Behymer, & Mersch, 2017).

Figure 2. IMPACT Operator-Autonomy Play-based Teaming Interfaces.

IMPACT: Intelligent Agent Framework for Course of Action Generation

Dakota Evans, Michael Hansen, and Scott Douglass

An intelligent agent was developed using the Cognitively Enhanced Complex Event Processing (CECEP) framework, a complex event processing framework with extended procedural and domain knowledge aspects. Agents that use procedural knowledge were developed using a discrete finite state machine (FSM) representation called behavior models that include states and transitions between states that are guarded by patterns. A pattern language called Esper matches complex patterns for behavior model state transitions. The developed IMPACT agent has a set of patterns related to operator interactions for play calling. Behavior models can also produce behaviors (e.g., feedback for the operator or UxV play assignment). Agents that use domain knowledge were developed using cognitive domain ontologies (CDOs). A CDO is a rooted tree structure with features that are connected via relations. CDOs can be processed using the artificial intelligence process of constraint satisfaction to produce configurations, possible worlds, or courses of action (COAs). In IMPACT, CDOs were developed to capture the domain for UxV play calling and produce COAs for play to vehicle(s) assignment.

The IMPACT agent serves as a decision aid to a multi-UxV operator. The agent is integrated with a UxV route planner (UxAS), Fusion framework, plan monitoring service (Rainbow), and UxV simulator (AMASE). The operator's play calls are used as a starting point for generating COAs, with the play type (e.g., air point inspect), presets (e.g., cloudy, windy), and optimization criteria (e.g., time, fuel) forming the basis of domain knowledge used to constrain and rank possible COAs. Figure 3 describes IMPACT's play calling process.

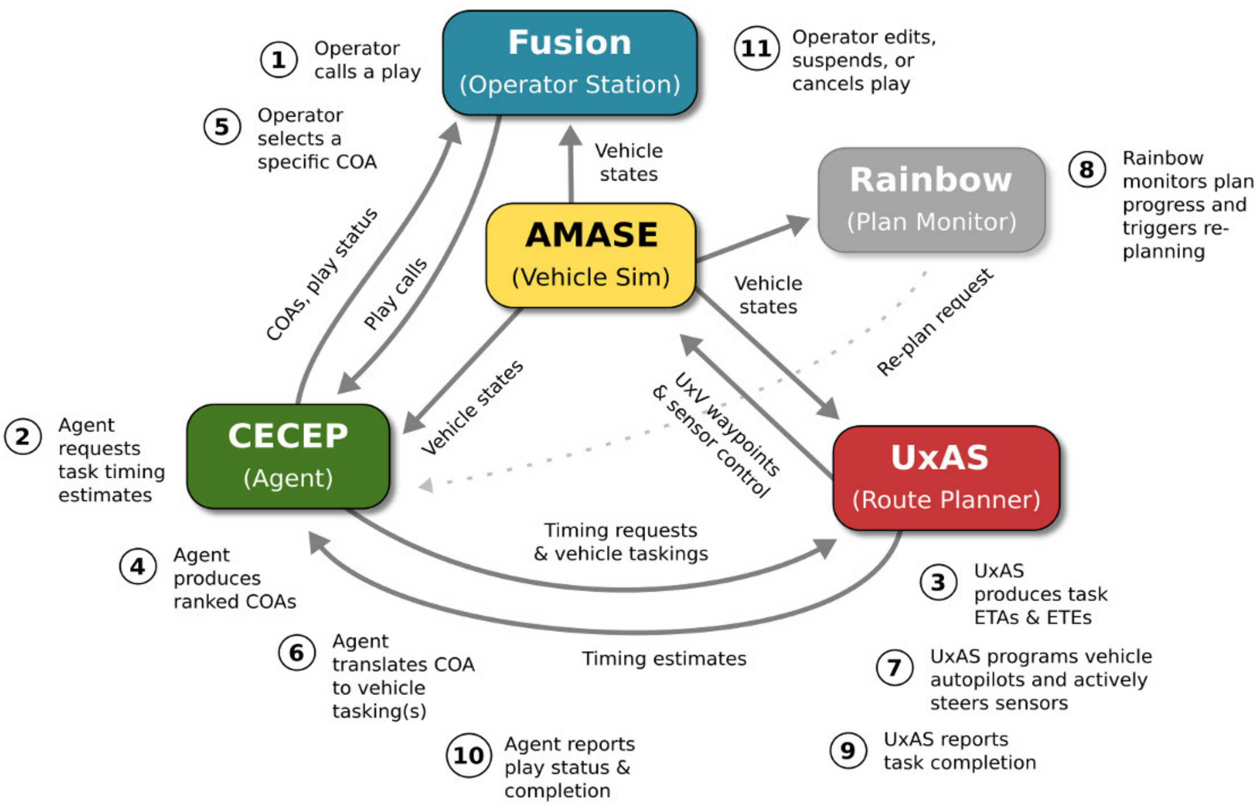

Figure 3. Play Calling Process in IMPACT.
(See list below for further information on each numbered item in the figure).

1. A play call commonly originates from the operator. However, the agent is capable of monitoring the vehicle locations and recommending opportunistic or serendipitous plays, such as inspecting the fuel dump by a vehicle already in the area.
2. The agent transforms play calls into lower level tasks for the UxAS route planner and requests task assignment utility from it (knowledge about task timings, fuel usage, and communications issues from the route planner).
3. The agent asserts the acquired knowledge to the play calling CDO domain representation.
4. The agent applies all constraints corresponding to the operator provided play details. The CDO is processed to produce all constraint compliant COAs. The agent uses an objective function to rank COAs and identify the Pareto optimal COA in a list and on a map presented to the operator (Hansen, Calhoun, Douglass, & Evans, 2016). A visual is also produced that allows the operator to compare COAs by solution utility. If no constraint compliant solutions exist the agent informs the operator.
5. The agent waits for operator acceptance, edit, or cancelation of a COA. Upon acceptance; the agent produces the vehicle action command to the UxAS to execute the COA.
6. The UxAS programs vehicle autopilots and actively steers sensors and sends other behaviors to the simulator.
7. The plan monitoring service monitors the active play and displays feedback to the operator if a constraint is violated (e.g., a UxV enters a restricted operating zone).
8. The agent waits for a task complete message from the UxAS.
9. The agent reports plan status to the operator to improve operator situation awareness.
10. The agent waits for operator to edit, suspend, or cancel the active play.

IMPACT: Fusion and the Distributed Architecture and Services

Sarah Spriggs, George Bearden, and Michael Howard

Fusion (Rowe, Spriggs, & Hooper, 2015) is a software framework that enables natural human interaction with flexible and adaptable automation. This is enabled by employing a distributed service oriented architecture that is composed of multiple disparate systems, unified representationally through negotiated communications protocols and physically through a common communications hub. The decentralization of the architecture enables logging, monitoring, and substitution of components with minimal effect on other components. Thus, several different systems can indirectly interact with one another through a publish/subscribe hub to provide a greater service to the user. All connected pieces communicate through a common messaging protocol to send and receive information. As a result, every component that connects to the hub has awareness of real time scenario and operator activity. Connected services developed for IMPACT include intelligent agent reasoning among disparate domain knowledge sources, autonomics monitoring services, intelligent aids to the operator, cooperative planners, and advanced simulation via instrumented, goal oriented operator interfaces. The distributed architecture along with an extensible software framework enables the system to be easily expanded for other human-automation research. For instance, modification of IMPACT is underway to support multiple stations whose operators share assets and potentially offload or gain tasks based on workload.

The Fusion architecture, as shown in Figure 4, includes the core (customizable) aspects that are common across applications as well as the features that support the IMPACT project. The Fusion test bed also displays the scenario environment, presents mission events that prompt UxV management tasks, provides a workspace for the operator to team with the autonomy in task completion, and records task performance measures. Other IMPACT specific components provide interfaces for calling and modifying plays, viewing agent generated candidate COAs, and presenting the results of an autonomics service monitoring play progress.

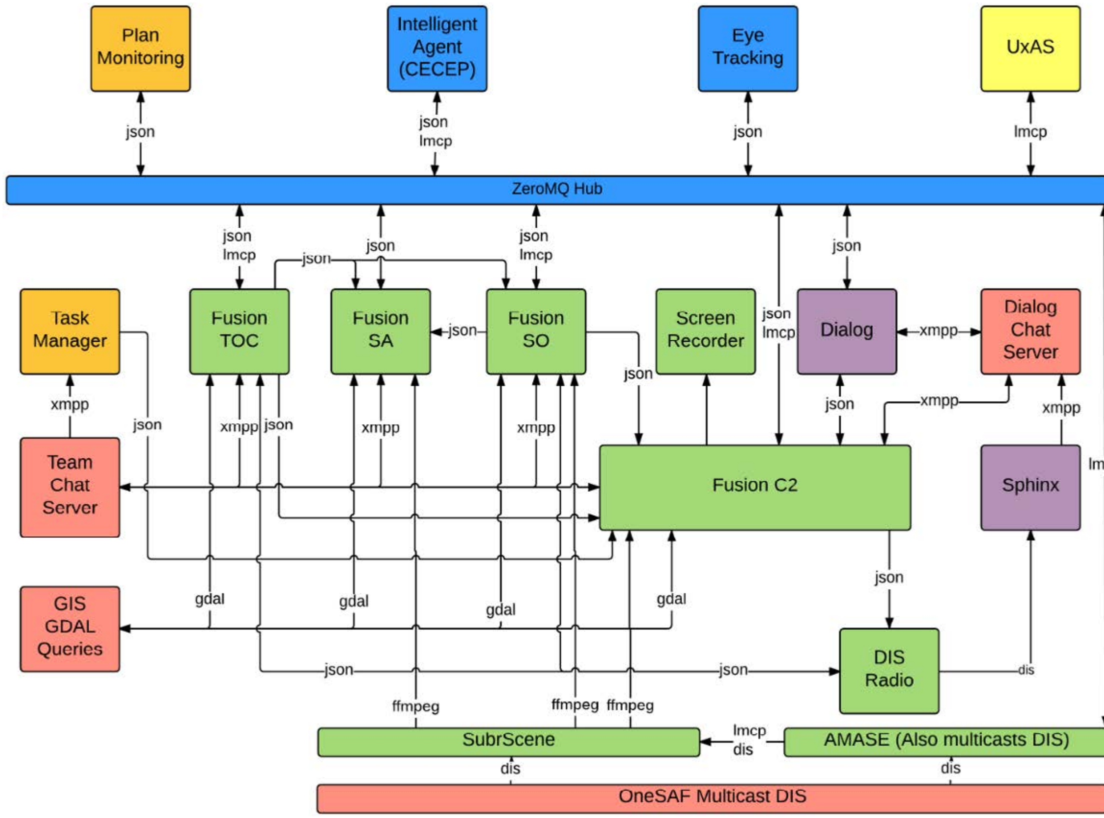

Figure 4. Illustration of Fusion and the Distributed Architecture and Services.

IMPACT: Operator-in-the-Loop Evaluation of Operator-Autonomy Teamwork
Kyle Behymer, Michael Patzek, and Allen Rowe

A high-fidelity human-in-the-loop simulation was used to compare the IMPACT prototype to a baseline system that represented the current state-of-the-art at the beginning of the effort. The baseline system included a subset of IMPACT's capabilities including the route planner and an associated interface. However, the baseline system lacked agent vehicle recommendation support, plan monitoring, and speech control. The experimental design was a 2 (Baseline, IMPACT) x 2 (low, high mission complexity) within-participant design with the order of conditions blocked by system (half of the participants used IMPACT first, the other half baseline) and counterbalanced across task complexity. Mission complexity was manipulated by varying the number and timing of tasks. Each of the eight participants familiar with base defense and/or unmanned vehicle operations performed four 60-minute base defense missions. Participants completed a variety of defense mission related tasks involving twelve simulated UxV. Participants' task performance was better on multiple mission performance metrics with the IMPACT system in comparison to the baseline system. Participants were also able to execute plays using significantly fewer mouse clicks with IMPACT as compared to baseline. The overall usability of each system was assessed using the System Usability Scale (SUS; Brooke, 1996). Participants rated IMPACT higher than baseline on all ten SUS items, and IMPACT's overall SUS score was significantly higher than baseline's overall SUS score. Participants also subjectively rated IMPACT significantly better than baseline in terms of its perceived value to future UxV operations as well as its ability to aid workload. In fact, every participant gave IMPACT the highest possible score for potential value, and all but one participant gave IMPACT the highest possible score for its ability to aid workload.

Way Ahead

The IMPACT project and its resulting control station prototype have enabled a deeper exploration into the critical issues that influence flexible and effective human-autonomy collaboration. Although the IMPACT evaluation demonstrated value in several aspects related to operator-autonomy teaming, several deficiencies were also identified and improvements are underway. These include novel methods enabling bi-directional communication and management of temporal constraints, more naturalistic dialogue and sketch interactions, and consideration of information uncertainty in decision-making tasks. Additionally, research is investigating the effects of increased decentralized replanning capability, real-time operator functional state assessment, and alternative team structures on overall human-autonomy teaming. The results will provide a much richer understanding of this area.

Acknowledgement

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