Applying DDDAS Principles to Command, Control and Mission Planning for UAV Swarms

Greg Madey (PI), M. Brian Blake, Christian Poellabauer
Hongsheng Lu, Ryan McCune, Yi (David) Wei

Department of Computer Science and Engineering

ICCS 2012
June 4, 2012

AFOSR Award # FA9550-11-1-0351
Unmanned Aerial Vehicles (UAVs)

• Trends
  – Numbers increasing
  – Costs decreasing
  – Nano to full sized
  – Swarms

Near Future

Distant Future

4 planes (MQ-X)

Swarm (Autonomous UAS)
Unmanned Aerial Vehicles (UAVs)

• Challenges
  – Operator overload
  – Flying a swarm
  – Training costs
Training Costs

Robowarriors Outnumber Fighter Jocks

This year, for the first time, the U.S. Air Force will train more UAV operators than fighter pilots. Some of those UAV operators were, for the first time, not already trained as pilots for other air force aircraft. The air force has long insisted that UAV operators already be manned aircraft pilots, and allowed most of them to spend only three years operating UAVs before returning to manned aircraft. This has limited the number of UAV operators available, and forced the air force to create a larger UAV operator training program than they would have needed if all UAV pilots were career UAV pilots. Some UAV pilots are now in it for their entire careers, and the air force is moving towards making it that way for all UAV operators. (StrategyWorld.com, July 17, 2009)
DDDAS Concept

• Simulations of the Swarms for Ground-based Operators
  – Mission Planning
  – Dynamic Mission Re-planning
  – Command & Control

• Agent-based Simulations
  – Dynamically Updated by UAV Sensors
  – What-if Predictive Modeling to Support Re-planning and Command & Control (Fly the Swarm)
Approach

1. Research Test-bed
   - Simulation-to-Simulation Modeling
   - Investigate DDDAS Research Questions

2. Hardware in the Loop
   - Quad-rotor UAVs
   - Evaluate, Calibrate and Validate Test-bed Results
Application of DDDAS Principles to Command, Control and Mission Planning for UAV Swarms

Research Test-Bed

<table>
<thead>
<tr>
<th>Agent-Based Simulator</th>
<th>Control Parameters</th>
<th>UAV Swarm Simulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java/MASON</td>
<td>System Software QoS Service Composition</td>
<td>MultiUAV2 - AFRL/RBCA</td>
</tr>
<tr>
<td>Abstract Simulation of Air Vehicles, Interaction with Environment and other Vehicles, and other Agents</td>
<td>Real-Time Sensor Feedback</td>
<td>6DOF Simulation of Air Vehicles Tactical Maneuvering, Sensor, Target, Cooperation, Route, and Weapons</td>
</tr>
<tr>
<td>Dynamically Updated Application</td>
<td></td>
<td>Sensor &amp; Air Vehicle Performance</td>
</tr>
</tbody>
</table>

How to ensure correctness and consistency in simulation that is dynamically updated?

Challenges / Possible Solutions
- Atomic execution/rollbacks?
- Deadlock detection?
- Software Eng Formal Methods
- Two phase commits?
- Checkin/checkout?
- Parallel execution paths?

How to ensure correctness and completeness of dynamically updated workflows?

The College of Engineering
at the University of Notre Dame
Detailed Design of DDDAS Testbed
Scalable DDDAS Architecture

Communicator (Service)

Proxy (Service)

Proxy (Service)

Proxy (Service)

Proxy (Service)

Private Cloud

VM Node 1
Simulation
Algorithm 1

VM Node 2
Simulation
Algorithm 2

VM Node 3
Simulation
Algorithm 3

UAV Swarm

UAV Swarm

UAV Swarm 3

The College of Engineering at the University of Notre Dame
The **Communicator** and the proxy services (**SimController**) are implemented as sending/receiving web services (the current testbed uses Tomcat as the service container).

- By associating unique IDs with DDDAS simulations (**MASON**), multiple instances can be associated with a single real-world instance (**MultiUAV2**).
Current Testbed: MultiUAV2-to-MASON Interactions

1. Create new MASON simulation;
2. Pass vehicle locations;
3. Pass target locations;
4. Pass vehicle waypoints;
5. Start MASON simulation
6. MASON simulation pass new waypoints to Communicator;
7. MultiUAV2 periodically polls the Communicator for updates.
Demonstration: Interactive Waypoint Updates

(UML Interaction Diagram)
DEMONSTRATION
Research Plan – Simulation/Modeling

• Challenge: How to maintain correctness of running simulation while injecting real-time sensor data
  – Investigate repeatable, principled approaches for modeling simulation state
  – Investigate specification approaches for governing simulation environments in context of real-life constraints
  – Creating real-time verification and validation approaches for on-demand assurance of correctness in simulated results
Challenge: When realizing DDDAS directives onto the real world, how to compose efficient/effective workflows on-demand considering highly dynamic resources.

- Investigate workflow composition approaches and dynamic programming approaches to apply services/tasks to dynamic resources (i.e. UAVs) with varying capabilities;
- Investigate efficient methods to execute DDDAS-oriented simulations in a commoditized cluster or private cloud environment.
- Investigate state-of-the-art architecture and system designs to support DDDAS in this context
Research Plan – Adaptive Sensing & Communication

Challenge – How to proactively adapt sensor routines to achieve efficient DDDAS communications

• **Adaptive Sensing** - Various sensing parameters, such as rate of sensing, sensor data aggregation/fusion, pre-processing and compression, etc., will be adapted to meet global mission goals (e.g., mission time, coverage, data quality)

• **Adaptive Communication** - Leverage availability of multiple wireless communication technologies (inter-UAV communications, UAV-ground communications, UAV-satellite communications) and the ability to adapt radio communications in response to varying traffic requirements and link qualities.

• **Adaptive Sensing and Communication for Decision Support** - Utilize DDDAS techniques to predict future network topologies, traffic requirements, mission objectives, resource constraints and availabilities, etc., to proactively adjust sensing & communication parameters and/or to impact other UAV swarm parameters (such as route planning, etc.)
Questions Now?

Later?

Greg Madey
gmadey@nd.edu

M. Brian Blake
M.Brian.Blake@nd.edu

This research was supported in part under a grant from the AFOSR Award # FA9550-11-1-0351