Report on the AFOSR Workshop on UAV Testbeds and Simulations

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The workshop was held in August following the contractors meeting to discuss the UAV testbeds that are currently being developed by several academic groups working with AFOSR and AFRL. The main purpose of the workshop was to bring the primary researchers together with the goals of:

- Developing a consistent and flexible simulation environment for the cooperative control problem. The primary roles of this simulation would be to facilitate communication between researchers (both academic and government) using a common platform with consistent assumptions. The scenarios and setup would be designed to focus on the role of uncertainty in the distributed control problem (either due to inconsistent or incomplete information).
- Establishing what UAV platforms are currently available. What demonstrations have been done, and what do we expect to show in the next 3 years?

The original schedule is given in Table 1, which was closely followed for the first day, but changed for the second to enable the conversations started earlier that morning to continue.

To a large extent, the primary objective of the workshop was accomplished - this was one of the first times that many of the PI's (see attendance list) had had a chance to talk over their hardware in more detail than is typically available in the DARPA and AFOSR contractor review time slots. The testbeds are discussed in detail in the slides, and Table 2 provides an attempt at a summary. Key topics and observations include:

- It is absolutely clear that, from an educational perspective (both graduate and undergraduate), testbeds are a great tool – they are exciting for the students to work on and they help us attract the best students at the university. Equally important, it is these students that will help transition the new technologies to AFRL/Industry through internships and jobs after graduation.
- Testbeds must include real vehicles, and for educational purposes, students would rather see N real vehicles for the tests, than 2 real and $N - 2$ virtual. That said, the vehicles must be robust and functional so that the focus of the effort is not on the vehicles but more so on the coordination and control system. The number of vehicles that is practical for ground operations currently appears to be on the order of 8. There are several indications that the equivalent number for air vehicles is 2 (several groups are having to work very hard to get 3 in the air for a coordinated experiment). We can expect this to increase with time as we develop more experience – but it indicates that tests with larger fleets ($N > 5$) with air vehicles might be too taxing to accomplish routinely, which is essential for this to be an effective testbed.

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- Researchers use vehicles both indoors and outside. Indoors provides more flexibility, but there is limited space. Working outdoors has significantly more complex logistics. Sensing for large-scale indoor operations is expensive. With GPS readily available outdoors, the cost of the vehicles for outdoor operations is currently not significantly greater than the cost of the ones used indoors. Obtaining access to large spaces to fly the UAVs is difficult – arranging short flight times at a larger facility would help overcome these limits.
- Most testbeds carry similar payload sensors (video), which are a good choice for surveillance and tracking. These are effective, but apply to only a few of the missions that UAVs might fly (see slides by P. Chandler). It was recommended that other payload sensors be investigated as well, such as RF detectors and/or Doppler radar. Since they have similar payloads, many of the teams are doing similar missions (video tracking and surveillance). It would appear that more use could be made of real-time video tracking software to provide feedback to the operator and/or the control system – this would be a good area for future collaboration.
- Many of the flight tests to date have focused on the vehicles, so there is room to improve the operational realism of the missions. Some missions have other vehicles (Roboflag and the MIT/BYU vehicle tracking examples, UW/OSU & Berkeley have also done tests tracking real vehicles). But in nearly all cases, threats and pop-ups targets have not been included in the environment. This realism needs to be enhanced to exercise the technologies better and improve the demonstrations – this is another possible area of collaboration.
- It was recommended that a living database of information and "lessons learned" be developed to continue these discussions. The most promising possibility would be to form a `wiki` which is a website that allows any user to add content, but also allows that content to be edited by others. Caltech currently uses MediaWiki[1]. MIT will set up a prototype to test out whether a page like this could be used to exchange hardware ideas/solutions and portable software[2].
- Several teams use extensive hardware in the loop simulations both to prepare for flights and as testbeds in themselves. There was general agreement though that the teams are probably not placing enough emphasis on using simulation environments as a stepping stone towards more sophisticated experimental demonstrations. *MultiUAV*[3] offers one such environment for simulating multiple UAVs, although further work is still required to include sensor models and sophsticated/dynamic environments.

  R. Murray recommended Gazebo[4], which is a multi-vehicle simulation environment built on open source tools that is often used by the robotic community. It supports both ground and air vehicles with some very detailed sensor models. It appears to provide a reasonable visual display of the environment. UAV models do not appear to

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[1] http://wikipedia.sourceforge.net/

[2] Location will be sent out by email

[3] S. J. Rasmussen and P. R. Chandler, "MultiUAV: A Multiple UAV Simulation For Investigation Of Cooperative Control," *Proceedings of the 2002 Winter Simulation Conference.*

[4] http://playerstage.sourceforge.net

exist at this time, but they are probably not too hard to develop. This might provide an excellent environment for the group to develop a consistent simulation for various mission scenarios.

In summary, I believe that the workshop met its main objectives and led to an very enlightening set of conversations. But it will be important to continue these dialogues, either in person or online, if the true value of these conversations are to be realized. As described in Table 2, the testbeds available offer a wide range of capabilities that should lead to some very sophisticated demonstrations in the years to come. The workshop also made it clear that there are several possible areas for future collaboration:

- Use a wiki webpage to exchange detailed hardware lessons learned, algorithms, and reports.

- Jointly develop real-time video tracking software to provide feedback to the operator and/or the control system.

- Jointly develop more realistic simulations and experiments to better exercise the control technologies.

- Develop and distribute models for Gazebo and/or environment models for MultiUAV.

Attendance List

S. Banda (AFRL/VACA)	R. Beard (BYU)	D. Castanon (BU)
P. Chandler (AFRL/VACA)	R. D'Andrea (Cornell)	E. Frew (UC Boulder)
J. How (MIT)	S. Heise (AFRL/AFOSR)	S. Jayasuriya (TAMU)
E. Johnson (GaTech)	T. McLain (BYU)	R. Murray (CalTech)
M. Orr (AFRL/VACA)	U. Ozguner (OSU)	A. Redmill (OSU)
Felipe Pait (AlphaTech)	K. Passino (OSU)	S. Rasmussen (AFRL/VACA)
S. Sastry (UC Berkeley)	J. Vagners (UW)	

Table 1: AFOSR Workshop on UAV Testbeds and Simulations

Wednesday	Oak Room	
1:00 – 1:05	Jonathan How	Introduction
1:05 – 1:40	Phil Chandler (AFRL/VA)	UAV Problem definition
1:45 – 2:15	Jonathan How (MIT)	Hardware UAV Testbeds
2:15 – 2:45	Raffaello D'Andrea (Cornell)	Experiences with previous collaborative activities on Roboflag
2:45 – 3:00	Break	
3:00 – 3:30	Shankar Sastry (UCB)	Berkeley Aerobotics testbed
3:30 – 4:00	Eric Johnson (GaTech)	Helicopter testbed
4:30 – 5:00	R. Beard & T. McClain (BYU)	UAV Testbed
5:00 – 5:30	U. Ozguner (OSU)	Multi-UAV testbed with air-ground collaboration.
6:30 – 8:00	**Dinner** **Soleil Private Dining Room**	For speakers and invited guests
Thursday	**Colorado Room**	
8:30 – 9:00	Richard Murray (CalTech)	Experiences with previous collaborative activities on the MVWT
9:00 – 9:30	Juris Vagner (UW)	UAV testbed
9:30 – 10:00	Steven Rasmussen (AFRL/VA)	Multi-UAV Simulation Software
10:00 – 11:00	Breakout Sessions	**Marengo** and **Board Rooms**
11:00 – 11:30	Report back	
11:00 – 12:00	Sharon Heise and Siva Banda	Comments and Wrap up

Table 2: Testbed Comparison

	MIT	Cornell	Berkeley	GATech	BYU	OSU	CalTech	UW
Vehicle Info								
Aircraft Qty & Price	8 $$		4 $	1 $$$	3 $	4 $		1 $$$
Gnd Veh Qty & Price	8 $$	8 $	4 $$				15 $	
Helicopter Qty & Price			2 $$$	1 $$	4 $	1 $$		
Hardware Info								
Autopilot	C	D	D	D	D	D	D	D
Sensor packages	C, IPS, GPS	C, GPS	C,GPS	C, GPS, S	C,GPS	C, GPS	IPS, S, C^5	C, GPS
Logistics								
Indoor/Outdoor	I/O	I	O	O	I	I/O	I	O
Company Support	No	No	No	Yes	No	No	No	Yes
Planning Approaches								
On/Off Board	Off	Off	On	Off	On/Off	On	Off	On/Off
Architecture	C	C→D	C/D	C	C	C	C	C
Missions Demonstrated	TA T	RF	S	T	R T	T	T RF	S
HWIL Sim capability	Yes	No		Yes	Yes		Yes	No→OEP
Environment	Sim	Real	Real/Sim	Real/Sim	Sim	Real	Real	Real

Code:

Vehicle Information
$	> $3K
$$	> $10K
$$$	> $50K

Hardware Information
Autopilot	C	Commercial Off The Shelf
	D	Developed
Sensors Packages	C	Camera
	IPS	Indoor Positioning Systems (Laser-Based)
	GPS	Global Positioning System
	S	Sonar

Planning Approaches
Architecture	C	Centralized
	D	Decentralized

Missions
	TA	Task Assignment
	S	Search
	T	Tracking
	R	Rendezvous
	RF	Roboflag

Environment
Real	Physical targets, obstacles, and threats
Sim	Simulated targets, obstacles, and threats

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