EXTENDING AUTONOMY CAPABILITIES FOR UNMANNED SYSTEMS WITH CRUSER

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Abstract

The paper introduces a field experimentation program developed and maintained at NPS for almost a decade and its latest expansion, Consortium for Robotics and Unmanned Systems Education and Research. It also presents some of the successful developments accomplished within aforementioned initiatives, including indoor and outdoor platforms.

1 Consortium for Robotics and Unmanned Systems Education and Research

The U.S. Special Operations Command – Naval Postgraduate School (NPS) Field Experimentation Cooperative was established a decade ago to explore viability of new Special Operations Force (SOF) technology concepts as solutions for identified current and future capability gaps, enhance SOF future capabilities by providing a unique education program, and provide unique interdisciplinary graduate education experience for students and research opportunities for faculty in which the latest technologies, concepts of operation, and human systems integration are evaluated for SOF applications in a field environment. These objectives are accomplished through a series of quarterly two-week long Tactical Network Topology (TNT) field experiments held in the restricted airspace of Camp Roberts, CA, where operations focus on air and ground based networks, networked sensors, unmanned / autonomous vehicles, and situational awareness.

Among others, a lot of experiments involve different aerial platforms. Figures 1 and 2a show just a few aerial platforms used in a variety of research projects and Fig.2b demonstrates an extent of the experimental efforts during a typical field experimentation week.

Fig. 1. A range of different aerial research platforms at NPS.

a)  b) 

Fig. 2. Some other platforms (a) and a fleet of vehicles involved in a typical field experiment at Camp Roberts (b).

Due to a huge interest to unmanned systems, at the direction of the Secretary of the Navy, the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) was recently established at NPS to provide a collaborative environment and build a community of interest on the application of unmanned systems in military and naval operations. CRUSER's intent is to provide a holistic collaborative environment, encompassing the breadth of unmanned systems, ranging from the technological challenges to even those dealing with cultural, ethical, political and societal issues. Controls, sensors, design, architectures, human capital resource requirements, concept generation, risk analysis and field experimentation are just a few interest points, with an emphasis on the necessity for greater interaction among disparate disciplines to innovate new capabilities or approaches.

The CRUSER community of interest comprises both individuals and institutions spanning academia, all branches of the military, government agencies, industry, and international organizations and members. With its membership since CRUSER's stand up in 2011 already swelling to over 600 members, CRUSER benefits from the information exchange, including a monthly meeting (including dial-in and video conferencing support) and a monthly e-newsletter, both of which are open to contributions and offer opportunities for members to share their ongoing projects, experiments, results, and/or other events. Additionally, CRUSER sponsors NPS student travel to participate in activities of relevance or of interest to their ongoing research, and welcomes opportunities to enrich both the students and the host program or event.

A pillar of the CRUSER initiative is to create opportunities for innovation and concept generation, and as such, facilitates numerous events like the Warfare Innovation Workshops that bring together young military officer students with young engineers and scientists from Navy labs, academia, and industry to ideate and develop novel concepts of operations, new capabilities, or next-generation technologies to address a relevant operational scenario. For example, an upcoming workshop in September 2012 once again leverages the diverse backgrounds its participants to innovate for unmanned systems applications relevant to the future of undersea warfare.

A second focal point of CRUSER is its field experimentation area, where the ideas developed in its concept generation events mentioned above are carried further to test and demonstrate those concepts in the field or fleet. This experimentation effort leverages not only the extensive facilities at Camp Roberts, but also the various venues and existing experimentation events throughout the Navy. This emphasis on proof-of-concept field experiments highlights the rapid pace of technological development in robotics and unmanned systems, and the necessity to collaboratively benefit from frequent lessons learned and experimental results. Near term plans for CRUSER include a dedicated, five-day field experimentation event for CRUSER-generated concepts and technologies, which expands upon the aforementioned opportunities to highlight experiments relevant to the overarching operational scenario.

Finally, CRUSER's namesake highlights the educational mission in the form of various robotics and unmanned systems education programs, ranging from the continuing alignment of relevant courses within the NPS to the spanning of collegiate, postgraduate, professional, and continuing education levels throughout the Navy. While the following section presents a couple of representative TNT/CRUSER research projects, the last section briefly introduces autonomous systems track at NPS and one of the laboratories supporting it.

2 Example Research on Extending Controlled Autonomy for UAVs

2.1 Autonomous Aerial Robot/Sensor Delivery System

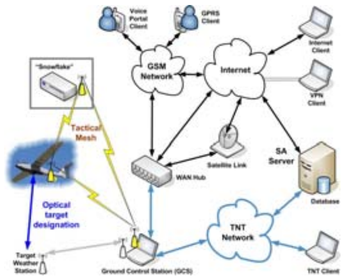
One example of a successful project within TNT/CRUSER is a development of a prototype of an autonomous aerial delivery system allowing autonomous delivery of payload, supplies, sensors, and ground robots to the stationary targets and onto moving platforms with unprecedented accuracy of 10 meters circular error probable.

The developed system (Fig.3a) consists of a Tier II class unmanned aerial vehicle (UAV), equipped with the autopilot and optical sensors (Fig.3b) to find and track targets and capable of carrying up to 30 kilogram of payload (in two containers under its wing). Once the intended point of impact is chosen a parafoil-based delivery system is deployed. These systems implement the best guidance and control algorithms resulting in a pin-point accuracy of delivery (Fig.3c).

a)  b)  c) 

Fig. 3. Deployment platform (a) equipped with a gimbaled camera (b), designed for accurate payload delivery (c).

Target assignment can be accomplished in several ways. First, the coordinates of the target(s) can be entered into the system during the pre-flight checks or in flight from anywhere in the world via the Internet (the system benefits of all its elements being networked and linked to the Internet (Fig.4a)). Another scenario is that the coordinates of the target are computed automatically by choosing any point within the image provided by on-board EO/IR sensor. Finally, the target coordinates can be transmitted from the ground with the help of the target ground weather station (Fig.4b). This optional component not only allows transmitting the coordinates of the delivery point itself, but also provides a very cheap and yet effective way of increasing accuracy of payload delivery by measuring and transmitting the ground winds. This palm-size device needs to be mounted at the desired target location, and may be deployed either with a vane, if a soft landing is needed, regardless the delivery direction, or without it, if a certain delivery direction is preferable (in the mountains). Day or night the requested payload will be delivered right to the target. Figure 4c shows an example of delivering a ground robot that proceeds with its own mission using an extended link via unmanned platform above it.

a) 

b)  c) 

Fig. 4. Network architecture (a), optional ground weather station (b) and example of a ground robot deployment (c).

2.2 Swarm versus Swarm Testbed

Another ongoing project is the development of swarm UAV capabilities to include design, fabrication, and deployment of large numbers of UAVs and the development of the software, hardware, network, and logistic infrastructure to support this research initiative. Further, this ambitious system-of-systems project is motivated by the need to explore mission-oriented capabilities requiring an emphasis on integration of technical and employment methods. The future operational scenario of interest is the use of unmanned systems in adversarial contexts, requiring exploration of technologies to counter these types of systems.

The NPS Many vs. Many Autonomous Systems Testbed currently in development facilitates future concepts and tactics for countering the adversary's unmanned systems. The vision for this unique experimentation testbed is to tangibly address the emergence of future asymmetric threats that will employ large numbers of unmanned systems. The immediate benefit of the testbed is the experimental exploration and validation of swarm vs. swarm tactics against the backdrop of combating autonomous agents in the aerial battlespace. The near term goal is to implement and analyze mission scenarios -- and the requisite autonomy technologies - involving 50 versus 50 unmanned aerial vehicles (Fig.5a) in large-scale, outdoor live-fly experiments, whereas the objective is to spur innovation in offensive and defensive tactics for successfully employing unmanned systems against those of the adversary.

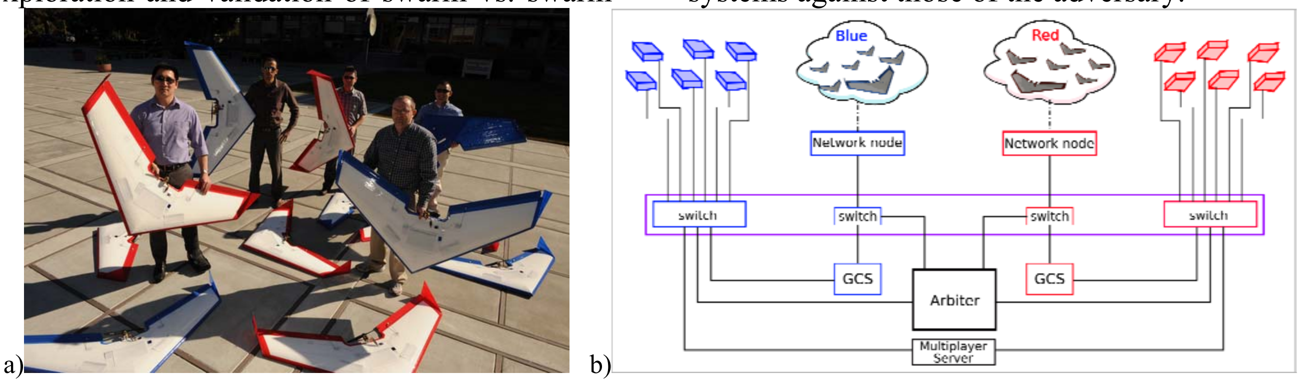


Fig. 5. Many vs. Many autonomous systems testbed (a), and its architecture (b).

The system architecture for field experimentation and deployment of the “swarm vs. swarm” testbed is shown in Fig.5b. The architecture includes physical and virtual networked UAVs and supporting ground control stations, mesh network capabilities, virtual environment simulations, and command and control nodes.

Enabling capabilities include open source technologies, e.g., vibrant open source software communities for robot operating systems and active development for open hardware designs for UAV autopilots, as well as commercial- and government-off-the shelf (COTS and GOTS) products (e.g., see Fig.1), to ensure that the research focus of the testbed specifically remains on advancing the state-of-the-art in tactics and their associated autonomy algorithms. Additional aligned topics include research thrusts in mission-level autonomy, human-robot interactions, bio-inspired tactics (such as swarming and active herding), test and evaluation methodologies for unmanned systems, and even policy implications for employment of swarming unmanned systems in modern warfare.

The system-of-systems testbed offers a new and unique capability to explore advanced tactics for unmanned systems and more specifically for countering adversarial unmanned systems. The focus on the development on tactics will effectively drive the development of engineered systems and supporting autonomy technologies, i.e., information gathering and processing algorithms, coordination among multiple agents, and appropriate levels of interaction between the system-of-systems and the commanders and operators. In this way, the operational end users can expand the vision of technological development, while the researchers can better relate the theory and science of autonomy to the mission objectives of the warfighters.

3 Autonomous System Engineering and Integration Laboratory

As mentioned in Section 1, providing a foundation of the modern unique first-class hands-on education and thesis research in the area of unmanned systems (UxVs) is another important component of CRUSER. The Autonomous Systems track offered at NPS in conjunction with the courses required for the standard Master’s of Science degree covers the critical technology areas related to autonomous systems modelling, analysis, design, and operation. The core courses of the track are:

Introduction to unmanned systems, Low-level control of unmanned vehicles, Unmanned vehicles navigation, High-level and discrete event control of autonomous systems, Computer vision, C^3 networks for unmanned systems, Collaborative control of multiple autonomous systems, and Unmanned systems design.

The final course in the above sequence is a capstone course that integrates the material into a design of (a component of) an autonomous underwater, surface, ground, aerial, or space system, its algorithm or sensor to be tested at one of the TNT or CRUSER experimentation events.

Additional courses related to autonomous systems may be taken as electives. Some of the available courses are Signal processing, MEMS-based sensors, Optimal estimation and data association, Electronic warfare systems, Adaptive / robust control, Network operating centres, Underwater acoustics, Virtual environments modelling and simulations, Joint campaign analysis, System-of-systems operational environment for UxVs.

There are multiple laboratories at NPS supporting the educational component of CRUSER. Among others the Autonomous Systems Engineering and Integration Laboratory (ASEIL) is dedicated to support studying unmanned platforms, payloads, weapons, command and control architectures, computers, communications, missions and concepts.

The educational component of ASEIL is based on a set of experimental setups provided by Quanser, Inc. The ASEIL possesses several linear and rotary control experiments allowing students to employ the same power plant to perform experiments of varying complexity and explore different feedback strategies such as PID, LQR, H_∞, fuzzy, neural nets, adaptive and nonlinear controllers. These include the flexible link and joint (to study vibration suppression and weapons aiming), gyro-stable platform and two-degree-of-freedom ball balancer (to learn about gimbaled platforms including those used in Inertial Navigation Systems), solar tracker module (to address missile guidance concepts and alternative to Global Positioning System (GPS) means for navigation), single and double self-erecting inverted pendulum (to study stability and controllability issues). By coupling the appropriate module to the plant students achieve configurations ranging from simple position servo control to advanced multiple-input multiple-output systems.

The fleet of ASEIL UxVs includes multiple indoor platforms, Quanser's Qball quadrotor and Qbot ground vehicles, equipped with a variety of sensors and capable of executing collaborative autonomous missions (Fig.6). The entire quadrotor is enclosed within a protective carbon fibre cage which gives the Qball a decisive advantage over other vehicles that would suffer significant damage if contact occurs between the vehicle and an obstacle. Both Qball and Qbot utilize digital-to-analog converters and the embedded Gumstix computer. They employ an optical motion capture systems (GPS substitute), high-resolution inertial measurement unit and avionics input/output card designed to accommodate a wide variety of research applications.

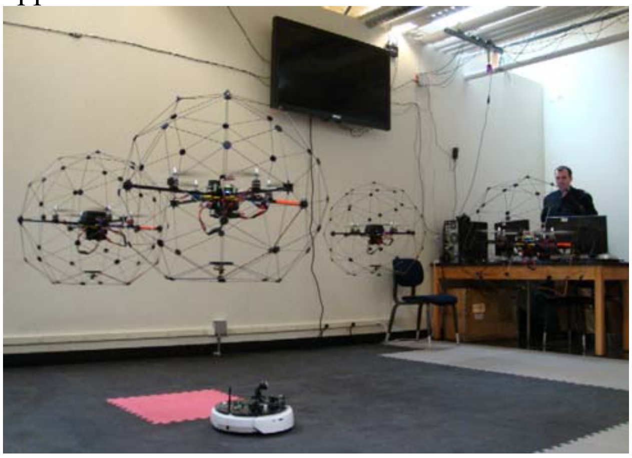


Fig. 6. Four hovering Qballs and Qbot on a joint reconnaissance mission.

These include the incorporation of traditional and developing of novel approaches in reactive and global navigation through the cluttered environment for the ground vehicles, formation flying and developing a see-and-avoid capability for quadrotors, exploring effectiveness of a variety of collaborative missions involving heterogeneous groups of UxVs.

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