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Overview of the University of Texas at Arlington's Autonomous Vehicles Laboratory

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Abstract

The University of Texas at Arlington (UTA) is in the process of rejuvenating its Autonomous Vehicles Laboratory (AVL). The AVL is concerned with answering a host of research questions related to engineering remotely-controlled, autonomous, and cooperatively-controlled unmanned aerial vehicles (UAVs). The AVL is equally concerned with providing undergraduate and graduate students with multidisciplinary engineering experiences in developing UAVs. This paper describes our plan for the UTA AVL from the vantage points of applications and curricula, and statuses laboratories and funding. A companion paper describes our plan for the UTA AVL from the vantage points of process and tools.

Keywords

Autonomous Vehicles Laboratory	autonomy
AVL	cooperative control
Environments	HLA
MAS	Multi-agent system
remote control	simulation methodology
UAV	University of Texas at Arlington
unmanned aerial vehicles	

1. Introduction

The world of Unmanned Aerial Vehicles (UAVs) is enjoying a period of significant expansion. UAVs have progressed from target drones to reusable weapon systems. Aerospace firms want to use UAVs as long-endurance platforms for data collection and even Internet infrastructure. UAVs of the future will be autonomous and will cooperate with each other to perform missions. UAV operators will be freed from attention to low-level stick-and-rudder-pedals controls, allowing them to concentrate on high-level maneuvers and tactics for a flight of cooperating UAVs.

This period of expansion calls for a pipeline of trained engineers and solutions to a host of research questions. The University of Texas at Arlington (UTA) Autonomous Vehicles Laboratory (AVL) was active during the mid- and late-1990s. The AVL entered the Association for Unmanned Vehicle Systems International (AUVSI) Aerial Robotics Competition as well as several other competitions. Its most famous design was the "Texas Tailsitter" (as seen on an episode of *Scientific American Frontiers with Alan Alda* [PBS]). The students who worked in the AVL in those days have since graduated. UTA Computer Science and Engineering (CSE) Senior Lecturer Arthur Reyes and Mechanical and Aerospace Engineering (MAE) Assistant Professor Atilla Dogan recently assumed responsibility for the AVL's future. This paper describes our plan for the UTA AVL from the vantage points of applications and curricula, and statuses laboratories and funding. A companion paper [UTA AVL] describes our plan for the UTA AVL from the vantage points of process and tools.

2. AVL Applications: UAVs

According to the recent *UAV Roadmap 2002-2027* published by the Secretary of Defense [Weatherington]:

"The U.S. military has a long and continuous history of involvement with UAVs, stretching back to 1917. UAVs had active roles in the Vietnam, Persian Gulf, and Balkans conflicts, as well as Afghan operations, providing critical reconnaissance in each. With recent technology improvements allowing more capability per pound, today's UAVs are more sophisticated and capable than ever. As the military's operational tempo has increased, so too has the employment of UAVs, to include performing a wider variety of missions than just reconnaissance. During the 1990s, DoD invested over \$3 billion in UAV development, procurement, and operations; since 2000, it has invested another \$1 billion and will likely invest over \$10 billion by 2010. Today, the DoD has in excess of 90 UAVs in the field; by 2010, this inventory is programmed to quadruple."

UAVs can be classified into three groups in terms of control architecture.

2.1. **Remotely-Controlled UAVs**

These types of UAVs are remotely controlled from a ground or shipboard station. The level of control varies from direct "stick control" to "flight path control". There is a yearly student competition that encourages the development of such UAVS. The American Institute of Aeronautics and Astronautics (AIAA) is a professional society. Through its Applied Aerodynamics, Aircraft Design, Design Engineering and Flight Test Technical Committees and the AIAA Foundation, it organizes the Cessna/ONR student Design/Build/Fly (DBF) competition every year. The contest provides a real-world aircraft design experience for engineering students by giving them the opportunity to validate their analytic studies. Student teams will design, fabricate, and demonstrate the

flight capabilities of an unmanned, electric powered, radio controlled aircraft which can best meet the specified mission profile. In the words of AIAA, "the goal is a balanced design possessing good demonstrated flight handling qualities and practical and affordable manufacturing requirements while providing a high vehicle performance."

We will configure the AVL to replicate and hopefully solve real-world problems faced by our industrial colleagues, such as Lockheed Martin Aeronautics (LM Aero). For example, UAVs of any sophistication feature embedded, real-time computer control. Computer Aided Software Engineering (CASE) tools can be used to develop the software for such controls, but CASE's potential productivity gains are often unmet. The idea behind CASE is to develop and maintain application software at the level of models and designs, rather than at the level of source code. One essential problem with extant CASE tools is that their notations for software models and designs are not expressive enough to account for all the nonfunctional requirements of the application software being developed or maintained. This means that after a CASE tool has generated a source code implementation from a model, the generated source code still needs to be manually modified so it will interface with other software, hardware, etc.

For example, many CASE tools for visual modeling support state transition diagrams. The intent of such diagrams is to model *nominal*, reactive behavior. If you add transitions to account for every possible exception and failure, the diagram becomes an unreadable rat's nest. Thus CASE tools need to be extended in some way to allow all requirements to be specified and correct source code be generated. For specifying responses to failures and illegal state/event combinations, you could use Binder's "response matrix" notation [Binder2000].

We will adopt one of LM Aero's processes for developing embedded software. LM Aero uses the Rhapsody family of product by I-Logix [Douglass] as avionics software design environment. Based on the software design specifications, Rhapsody automatically generates source code. The AVL will provide the perfect means of investigating these problems while developing our own UAV software, and hopefully find solutions along the way.

2.2. Autonomous UAVs

Our contacts at LM Aero inform us that autonomous UAVs will become a reality only if their concerns can be practically addressed: software reliability, testability, performance, safety, and certifiability. Autonomy implies application of artificial intelligence (AI) techniques. The problem with search-based AI techniques is that search can become stuck or lost, which is unacceptable when human lives are at stake. The indeterminacy of search-based techniques raises many risks for safety-critical systems such as UAVs.

AUVSI has instituted a number of student competitions requiring vehicular autonomy [AUVSI]:

"In 1990, AUVSI realized the need to introduce future generations of engineers, scientists and operators to unmanned systems. To that end, AUVSI has created three different Competitions to challenge students to design, build and deploy air, ground and underwater autonomous

unmanned systems. The missions and requirements for each Competition vary but the common thread in each is the requirement for autonomous operation: The entries are not remotely controlled but are programmed to sense their surroundings and respond accordingly, independent of any external control by an operator. These Competitions have captured the imagination of students, industry, the media and the public as they have been featured on The Discovery Channel, Scientific American Frontiers and other television, radio and print outlets around the world. One of the competitions by AUVSI is student UAV competition. The goals of this competition are to challenge a new generation of undergraduate university engineers to design and build unmanned aerial vehicles (UAVs) capable of performing realistic autonomous missions in an aviation environment, and to foster ties between young engineers and the organizations developing UAV technologies.”

We believe SBD can provide higher levels of assurance for software reliability. State transition models developed with a CASE tool can be executed within an emulator. We can feed the emulator input data drawn from what we believe will be the application program's operational profile. The emulator can log failures. Based on these data, we can use the discipline of software reliability modeling [Musa+] to quantify our assurance levels.

We are planning to use a tool like Computer – Aided Rate Modeling and Simulation (CARMS), an integrated Markov modeling and simulation tool. The features of which would include a state transition diagram based on environment for model setup, a spread sheet-like interface for data entry, an expert system link for automatic model construction and an interactive graphics interface for displaying simulation results. The tool which we would use will be a general purpose tool suitable for reliability, maintainability and availability. By using such a tool for analysis, complex design cycles can be shortened, simplified and better understood and documented.

2.3. Cooperative UAVs

The AUVSI International Aerial Robots Competition (IARC) is designed to challenge students and industry to work together to achieve a common goal. This goal is to survey a simulated disaster site and determine the location of survivors and potential hazards. For example, the DeVRY team has incorporated a multi-vehicle system that consists of both aerial and terrestrial units. By using a wireless communication system, these autonomous vehicles are capable of interacting with one another to complete the required elements of the competition.

Thus UAVs of the future will be “agents” in larger “multi-agent systems” (MASs). Each UAV agent in a MAS could be mass-produced, and therefore inexpensive. Redundancy would occur at the level of UAV agents, not at the traditional level of UAV subsystems. MASs are characterized by “emergent behavior”, where the behavior of the system of agents as a whole is not what would be expected considering the behavior of

agents in isolation [Ferber1999]. It is tempting to consider how emergent behavior itself could be used to accomplish the mission, much in the way of colonies of ants or schools of fish. Designing the communication topologies and cooperation protocols of a MAS is a challenging engineering problem. If each UAV agent is micro-sized [JCKCK], the design tradeoffs will be even more systemic and critical. Because emergent behavior stymies top-down synthesis of agent designs from high-level MAS requirements, we propose a simulation-based design (SBD) method [CBD] that allows for evolutionary search through the MAS design space at various layers in the UAV/MAS design hierarchy. You can read about how the UTA AVL plans to apply SBD in the companion paper [UTA AVL].

2.3.1. UAV Cooperation Under Communication Constraints

Coordination and cooperation of multiple UAVs is a key enabler for full utilization of UAV systems. Although the addition of individual UAVs operating autonomously would be beneficial to a mission, groups of UAVs operating under an effective coordination strategy will perform much more efficiently. However, development of cooperative control strategies for UAVs poses theoretical and technical challenges [MCP].¹

One of the challenges is the incorporation of communication constraints into the development and assessment of cooperative control strategies. Terrain occlusion, range effects, bandwidth limitation and power consumption are a few examples of communication constraints. The type of control architecture will determine the level of autonomy of individual UAVs and the communication requirements. Two opposite ends of the spectrum are fully centralized and completely decentralized control architectures. In the case of fully centralized control strategy, the individual UAVs do not have much autonomy and need to be remotely piloted by a central control station. This requires continuous uplink and downlink of data. Currently, UAVs are attempting to pass progressively large volume of data through a limited-bandwidth communication infrastructure and on to an intelligent exploitation system that cannot process all the data it already received [Meyer]. A completely decentralized control architecture might give a full autonomy to individual UAVs. In this case, communication among the cooperating UAVs is needed for a cooperative mission planning and execution. Depending on the control architecture, the amount of bandwidth requirement for mission with a certain number of UAVs will be different. Alternatively, the control architecture will determine the number of UAVs that can be supported with a limited amount of bandwidth.

The AVL will be utilized to plan or analyze missions executed by cooperating UAVs. Among the problems that the AVL will study are: (i) design a mission so that the communication constraints will not be violated, (ii) dynamically re-plan a mission during the execution if the communication constraints are likely to cause a mission failure or (iii) regulate data transmission frequency or adjust data type to stay inside the communication constraints during a multi-UAV mission.

For cooperative control design and analysis, in addition to modeling of communication among UAVs or between UAVs and the central control station, modeling of dynamics and control of individual UAVs is needed. We have already developed

nonlinear 6 DOF aircraft equations of motion including the aerodynamic coupling due to trailing vortex. The vortex effect on the aerodynamic forces and moments acting on individual UAVs is included by computing effective wind components and wind gradients at the center of mass of the UAV. Examples where the aerodynamic coupling is significant are close formation and aerial refueling flights. The equations of motion are used to develop simulation models in MATLAB/SIMULINK environment. The communication protocols will be simulated using OPNET. The whole system of multiple UAVs cooperating with each other will be simulated as a HLA federation with UAV dynamics and communication protocol. Subsystems such as dynamics and control in SIMULINK and communication network in OPNET will be the federates of the HLA federation.

2.3.2. Coordinated Jamming Capability (CJC)

[DR] describes an example of a CJC application that “is cooperative search and jamming of enemy anti-aircraft (AA) radars (i.e., and air defense suppression mission) via hierarchical teams of cooperative, autonomous, aerial robots.” The robots are divided into three types: master, worker, and supervisor. Master robots are responsible for distinguishing between friendly and enemy AA radars. They are equipped with sensors for long range communication, but are ill-equipped to pinpoint the location of enemy AA radars. On the other hand, worker agents are equipped with low range, high accuracy sensors and jammers. The supervisor relays communications from masters to workers.

In the CJC application the MAS is a flock of different types of agents. The masters locate the enemy AA radars and move the flock towards the targets. If the targets are separated by large distances or there are more targets than masters, the flock splits into groups (one group per target). The sub-flocks move closer to the targets, but once again there may be more targets than sub-flocks—the supervisors simply divide into subgroups and continue approaching the targets. When a subgroup is close enough to a target, the workers detect the target with their high-accuracy, short-range sensors and jam the target. Workers are capable of determining if a particular target is being jammed, and will not engage the target, thus avoiding a wasteful attack.

2.3.3. Cognitive-based Agent Management System

The UTA AI Lab is conducting research using a Multi-Agent System (MAS) based on cognitive science attention theories in humans to develop the Cognitive-based Agent Management System (CAMS). CAMS is used to develop further combinational theories exploring cognitive science principles with current and historical work in artificial intelligence. The goal is to develop a cognitive architecture to embody an agent that interacts in virtual environments and eventually in the real-world as robotic entities. This architecture is comprised of many agents each doing a specific task to the best of its ability in an effort to capitalize on Gestalt principles of the whole being better than the sum of its parts. Since our agents often portray the heroic agent in scenarios, the architecture has been named the D'Artagnan Cognitive Architecture (DCA, from Dumas' *The Three Musketeers*). We have had some initial success with CAMS::DCA playing in virtual entertainment environments [Youngblood].

CAMS::DCA agents are being developed to operate using HLA and interact in virtual environments and scenarios generated by OneSAF (military simulation tool

[OneSAF]). DCA is being used to control entities such as vehicles, aircraft, and dismounted infantry in this environment. In cooperation with AVL, CAMS::DCA and AVL research can interact in simulated environments in the same HLA federations under OneSAF-generated scenarios. Through this level of interaction we can improve the artificial intelligence of CAMS::DCA as well as validate AVL vehicle control strategies when interacting with various entities either in cooperative or combative roles.

3. AVL Curricula

We plan to use the UTA AVL to enhance several current courses as well as to develop new, joint courses between the departments of Computer Science and Engineering and Mechanical and Aerospace Engineering. We plan to enhance three, 1-semester long courses in the MAE department: MAE 3305 Flight Dynamics, MAE 4310 Introduction to Automatic Control, and MAE 3303 Aerodynamics of Compressible Flows. Each course will be augmented with a term project to be performed within the AVL. The MAE 3305 project will create flying qualities simulations from aerodynamic data derived from UAVs under development in the AVL. The MAE 4310 project will give students the opportunity to design and evaluate control laws for UAVs under development in the AVL. The MAE 3303 project will require students to perform wind tunnel testing on UAVs or subscale models thereof and make corrections for scale effect, noise, etc.

We plan to enhance the 2-semester senior design course sequences for both the departments of CSE and MAE. The enhancements are options that seniors can exercise if they choose. The CSE sequence is CSE 4316/4317 Computer System Design Project I and II. The MAE sequence is MAE 4350/4351 Aerospace Vehicle Design I and II. A multidisciplinary team will be formed by seniors in CSE and MAE who choose this option. Each multidisciplinary team will develop a UAV and enter it into one or more AIAA or AUVSI competitions. Teams will apply SBD in the AVL. As described in the companion paper [UTA AVL], SBD in the AVL will use the IEEE/DoD High Level Architecture (HLA) for Modeling and Simulation [DFW1997]. CSE team members will apply their knowledge of computers and networks to develop HLA federates representing UAV subsystems with these characteristics. CSE team members will base such federates on commercial off-the-shelf (COTS) products such as OPNET Modeler [OPNET]. MAE team members will apply their knowledge of aerodynamics, aircraft design, vehicle dynamics, and control design to develop HLA federates representing UAV aspects and subsystems emphasizing those characteristics. MAE team members will base such federates on COTS products such as the Matlab family of products: Simulink [Simulink], Stateflow [Stateflow], and Real-Time Workshop [Real-Time Workshop]. The multidisciplinary team will design the HLA federation together, with the CSE team taking the leadership roles.

We plan to offer a new course jointly taught by Reyes and Dogan: Cooperative Control. Cooperative Control will feature reduced prerequisites that will allow both CSE and MAE students to enroll. Cooperative Control will review vehicle dynamics and control (because the CSE students will most likely not have learned this beforehand) and communication network design and analysis (because the MAE students will most likely not have learned this beforehand). Cooperative Control will emphasize trade-offs over the spectrum of centralized vs. de-centralized communication topologies.

4. AVL Status

The UTA AVL has several facilities at its disposal: the Wind Tunnel Laboratory (WTL), Machine Shop (MS), Computer-Aided Control System Design (CACSD) Laboratory, Software Engineering Center for Telecommunications (SECT), and the Artificial Intelligence (AI) Laboratory. Each lab's computers will host the HLA runtime infrastructure (RTI).

The WTL and MS will be used for UAV part manufacture, integration and testing, wind tunnel testing, and group meetings.

The CACSD features a network of Sun workstations: A Sun Blade 2000 is used as the server and three Sun Blade 150 are the clients. MATLAB/SIMULINK is available in the network, and will be used to develop simulations as well as execute them via an HLA compatibility add-in.

The SECT is where UAV embedded software will be developed. SECT will host computer-aided software engineering (CASE) tools from Rational Software Corp. and I-Logix Corp. The SECT will also host servers for configuration management, change management, and process management.

The AI Laboratory will support federation development and execution by hosting OPNET Modeler [OPNET], OneSAF [OneSAF], and D'Artagnan Cognitive Architecture (DCA) [Youngblood].

The AVL has received a seed grant from Lockheed Martin Aeronautics. The grant gives us the resources needed to become competent developing HLA federations.

Reyes and Dogan have written several accepted papers describing the AVL, its applications, and challenges.

- Reyes, A. Dogan, "Simulation-Based Development of Real-Time, Embedded Software for Swarmed, Autonomous Aerial Vehicles" to be presented at *AIAA/IEEE Digital Avionics System Conference 2003*.
- Reyes, A. and Dogan, A., "Autonomous Vehicle Lab Initiative at UTA", to be presented at the 2nd AIAA Unmanned Unlimited Systems, technologies, and Operations – Aerospace, Land, and Sea Conference and Workshop and Exhibition, 2003.
- Venkataramanan, S. and Dogan, A., "Vortex Effect Modeling in Aircraft Formation Flight", to be presented at *AIAA Atmospheric Flight Mechanics Conference, 2003*.
- Dogan, A., "Probabilistic Approach in Path Planning for UAVs", to be presented at *IEEE International Symposium on Intelligent Control, 2003*.

5. Future Work

We are seeking sponsors and additional funding for the AVL. A faculty member at UTA's Automation and Robotics Research Institute (ARRI) is interested in working on AVL projects with us. Together we are working to obtain equipment and supplies from ARRI's industrial partners.

During the summer of 2003, we will write at least one joint research proposal with colleagues from Lockheed Martin Aeronautics in nearby Fort Worth, Texas. Together we will target large, federal funding agencies such as DARPA, AFRL, and ONR. Also, we plan to submit a proposal in mid-June 2003 to the NSF Division of

Undergraduate Education (DUE) Course, Curriculum, and Laboratory Improvement (CCLI) Educational Materials Development (EMD) program [NSF].

To keep the AVL's projects focused and prioritized, we will target the following AIAA and AUVSI student competitions.

Table 1 Targeted AIAA and AUVSI Student Competitions

date	competition name
2004-04-23	AIAA/ONR Design, Build, Fly 2004
2004-06-01	AUVSI 12th Annual Intelligent Ground Vehicle Competition
2004-07-17	AUVSI Student UAV 2004
2004-07-20	AUVSI Aerial Robotics 2004
2004-08-07	AUVSI and ONR's 7th Annual International Autonomous Underwater Vehicle Competition
2005-04-23	AIAA/ONR Design, Build, Fly 2005
2005-06-01	AUVSI 13th Annual Intelligent Ground Vehicle Competition
2005-07-23	AUVSI Student UAV 2005
2005-07-24	AUVSI Aerial Robotics 2005
2005-08-07	AUVSI and ONR's 8th Annual International Autonomous Underwater Vehicle Competition

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