Experimental Facilities at UCLA

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Cooperative Control of Distributed Autonomous Vehicles
in
Adversarial Environments

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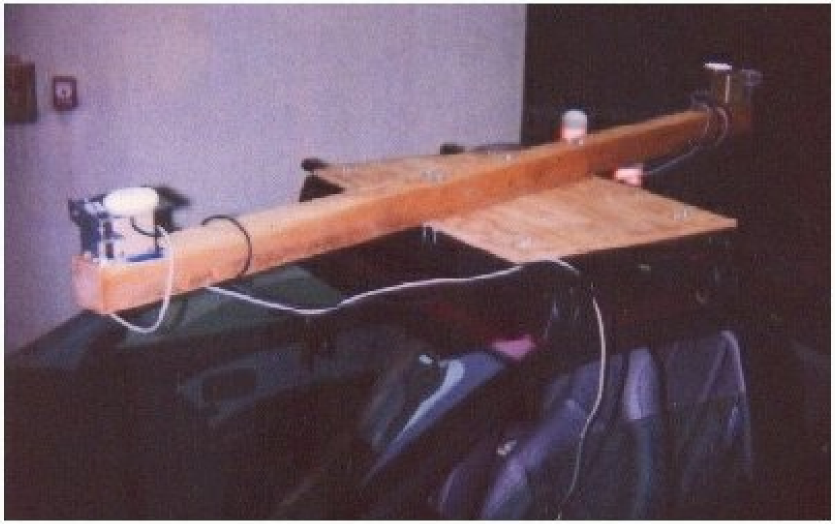
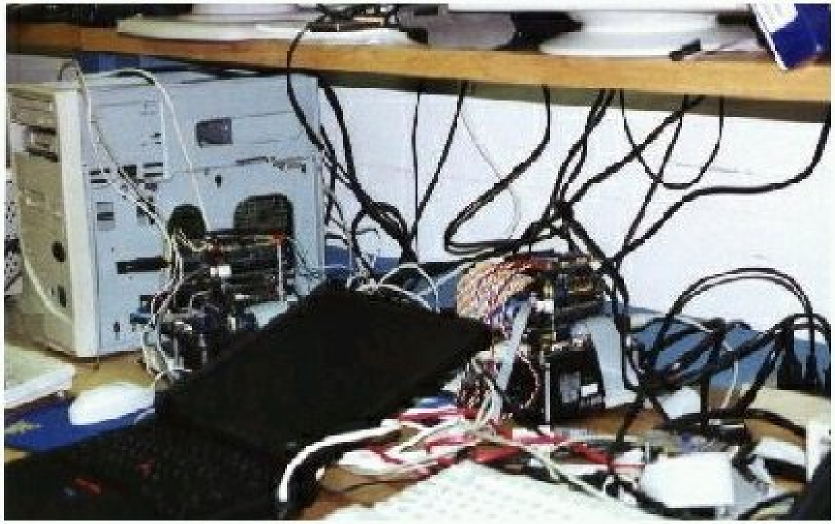
Background

- Much of our current capability comes from our formation flight programs.
  - UCLA developed flight control computer for investigations of aircraft formation flight for drag reduction.
  - Currently developing formation flight instrumentation system for use on test flights with F-18 research aircraft, in partnership with Boeing and NASA DFRC.
  - Facilities have expanded to include extensive bench testing and hardware in the loop testing.
  - Vehicle testing facilities on automobiles and in UAVs.

- Currently attempting coordinated autonomous flight of a pair of UAVs.
  - Vehicles are the "Mule" at UCLA and the "Frog" from Naval Postgraduate School.





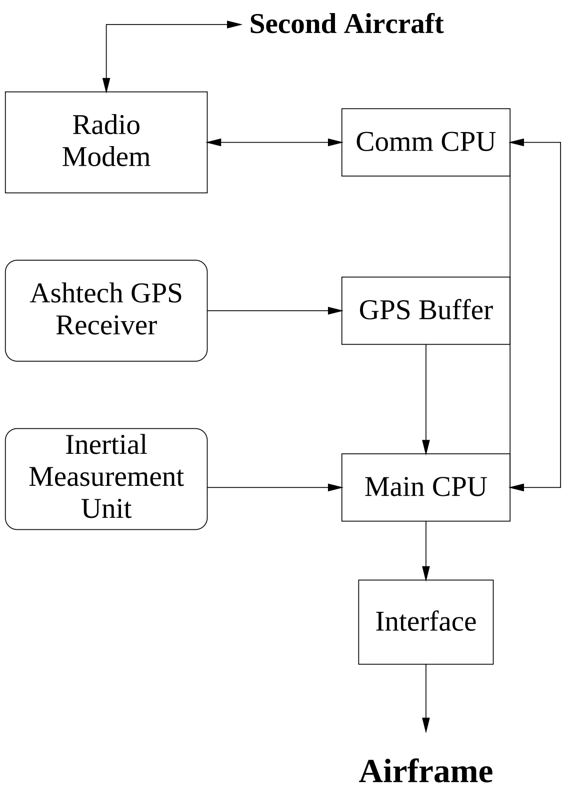
Formation Flight Instrumentation System

- Designed to provide highly accurate relative position, velocity, and attitude between aircraft.

- Primary purpose is formation flight for drag reduction.
  * Requires very accurate relative information, with less emphasis on inertial information.

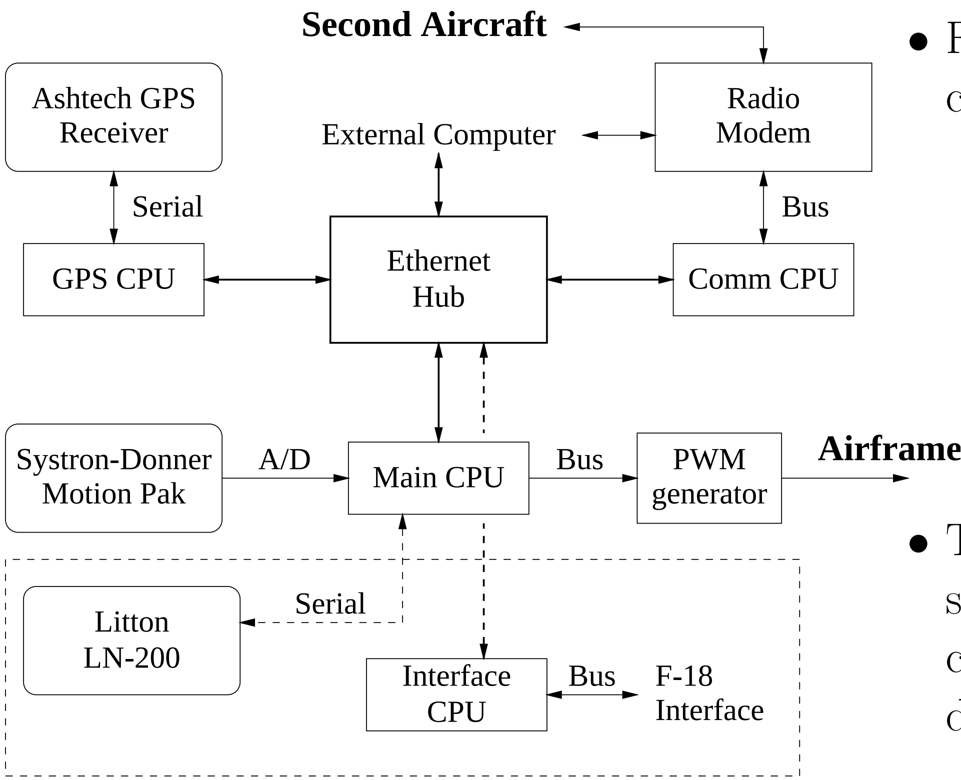
- Uses integrated GPS/IMU system.
  * GPS provides common inertial and timing reference for all vehicles
  * IMU provides measurements of high frequency motion and angular motion.
  * Differential Carrier Phase GPS provides extremely accurate relative range measurements.

FFIS Functional Description



- The radio modem provides communication with the second aircraft
  - ∗ Can also provide communication with external equipment.
- The basic functioning of the FFIS is independent of the airframe interface.

FFCC Hardware Architecture

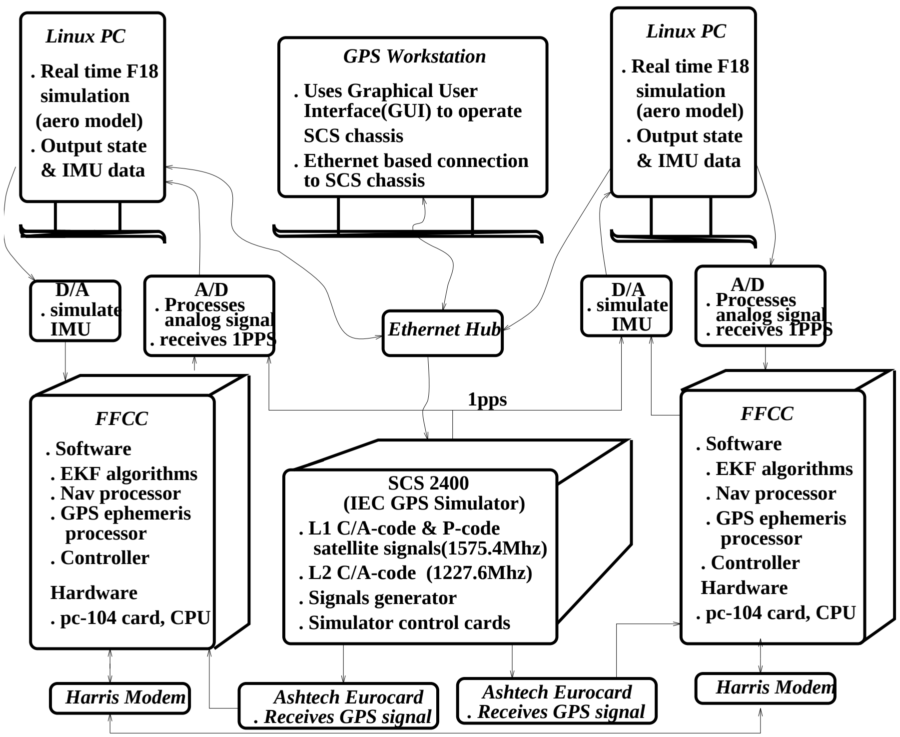


- FFCC is FFIS with control capability included.
  - ∗ Control for Mule is done through pulse-width-modulation output to standard R/C (hobby) actuators.
  - ∗ Control law is implemented in main CPU.
- The GPS requires a serial connection. A single-board computer allows communication without complicated software additions to main CPU.

Shown is current architecture; the dashed box includes additions for F-18 flight and upgrades to new IMU.

Hardware-in-Loop Simulation Facility

HiL Simulator Architecture



- Currently configured for F-18 simulations.
  - ∗ Aerodynamic simulation will be replaced with Mule simulation.
- For Mule simulation will be extended to include actuator hardware, rather than simulated actuators.
- Can (easily?) be extended to other aircraft and other vehicle dynamics.

Satellite Constellation Simulator

- 24 channels, divided between two RF outputs.
  * Configured to provide L_1 and L_2 signals from six satellites on each RF port.
  * RF ports feed directly to antenna ports on GPS receivers.

- Position, orientation, and rates of change delivered via ethernet from vehicle model workstations.

- SCS provides the 1 pulse-per-second signal to synchronize all parts of the simulation.

Aircraft Simulation Workstations

- Dual-processor Xeon workstations.
- Linux operating system.
  * Free, fast, flexible, runs in many flavors on a great deal of hardware.
  * Allows full control of background processes and direct access to hardware.
  * Sometimes difficult to get drivers for add-on cards.
- Synchronized every second to 1PPS signal from SCS.
- IMU signals simulated using D/A card in A/C workstations.
  * When IMU is upgraded to Litton LN-200, IMU simulation will be done using external device.

The Mule

- Remotely piloted aircraft, originally purchased for another program.
  - Aerodynamics designed to mimic ultra-light solar-powered aircraft.

- Physical characteristics
  - 17-foot wingspan, inverted V-tail.
  - Two-cylinder, 200-cc (approximately 13 hp) engine.
  - Current takeoff weight: 155 lb. (includes 10-lb payload)
  - Total payload: Greater than 30 lb.

- Used in flight tests on Formation Flight program since 1996.
  - Autonomous flight using previous flight control computer in 1997.

UAV Test Facilities

- Conducted at the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS)
  * Center run by Naval Postgraduate School
  * Flights take place at McMillan Airfield on Camp Roberts, near Paso Robles, California
- Several very convenient features:
  * Airspace management
  * Frequency management
  * Physical infrastructure: power, hangar, paved runway.
- UAV's operated by professional R/C pilots.

Hybrid Test Facilities

- Esssential tradeoff in a testbed is to include sufficient complexity to rigorously test algorithms without bringing in difficulty in analysing results.
  - A very simple hardware device may not provide sufficient flexibility.
  - A more complex hardware device introduces difficulties of modeling, construction, actuation, maintenance, et cetera.

- We desire vehicles of military interest – this is not feasible in a manageable testbed.

- Our major "hardware" restriction is likely to be communication.
  - Vehicle modeling can be done well, given sufficient time and incentive.
  - Communication is very environment dependent, and subject to bandwidth constraints, interference, power limitations, and other difficulties.

- We attempt to create a testbed that allows us to test our algorithms, rather than our mechanical abilities.

Proposed Facility – "Pseudo-Vehicles"

- Use computation to simulate vehicles; use hardware to implement communications.
  - Single-board computers are inexpensive and sufficiently powerful to model fairly complex vehicles.
  - Each "vehicle" will maintain its own state information, sensor models, and some local environment modeling.
  - SBCs will communicate with each other using wireless. Uncertainty can be allowed to arise naturally, and can be imposed through software or physically.
- Such an approach allows for complex, high-capability vehicles and includes necessary hardware uncertainty.

Proposed Facility – Environment

- One or more powerful coordinating computers will handle the environment and tell each machine if it has been damaged, what its sensors should see, et cetera.
- Coordinating machines will communicate with the SBCs via hardline ethernet. Given current network capacity, it is feasible to update environment variables within a reasonable control time frame.
- Existing hardware in the loop capability can be incorporated to create a "truth model" against which the performance of the pseudo-vehicles can be evaluated.