Aero Beam: a Testbed for Cyber-Physical System Education

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Overview

- Teaching Cyber-Physical Systems
- UAV Stabilization and Control
- Aero Beam Hardware
- Aero Beam Control
  - Accelerometer
  - Multi-sensor fusion with gyro
- Stabilization Results

Cyber-Physical Systems (CPS)

Cyber-physical systems (CPS) can be described as smart systems that encompass computational (i.e., hardware and software) and physical components, seamlessly integrated and closely interacting to sense the changing state of the real world.

NIST CPS Workshop Report, 2013

Examples: self-driving car, networked thermostat, ...

Cyber-Physical Systems (CPS) Example

An *internet of things* thermostat has a network connection and a web interface where you can manually set the target temperature from your phone.

A *cyber-physical system* thermostat determines heat demand by combining your travel schedule with a solar heating estimate derived from the predicted weather.

Cyber-Physical Systems (CPS) Education Needs

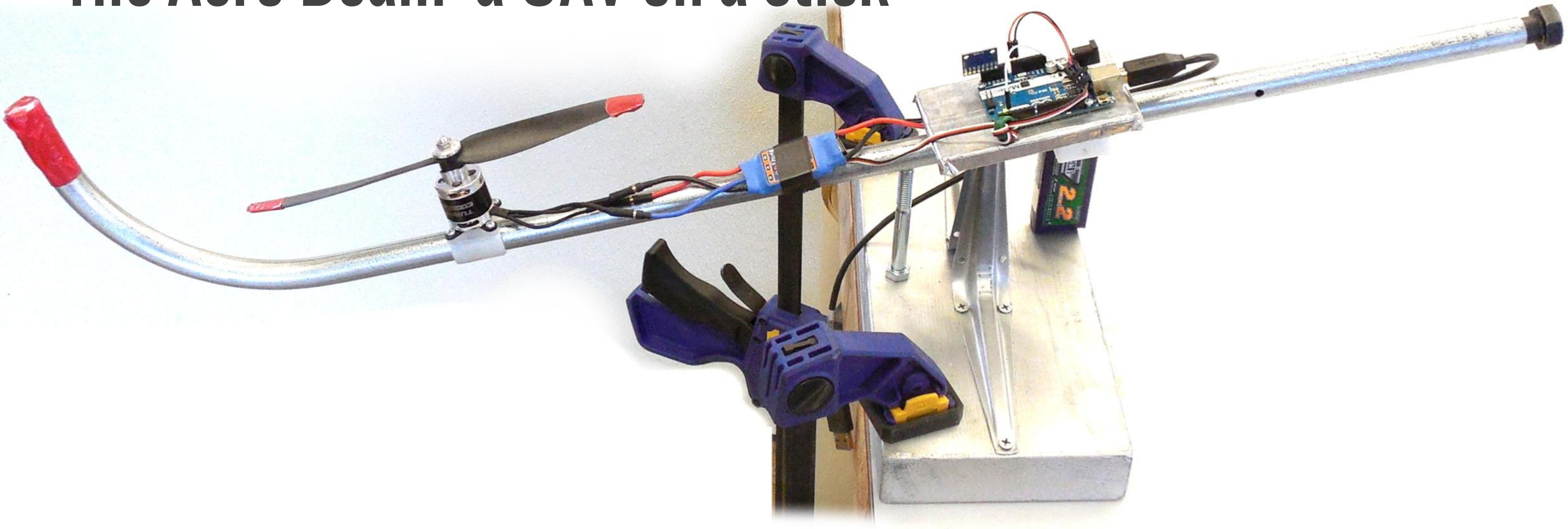
- **CPS education is needed everywhere:**
  - Workforce development and improvement
  - Academic research
  - Primary & secondary school education

- **Key enabling technology: hands-on *testbeds***
  - Let people experiment with the technology in real hardware
  - Often simpler than real applications, easier to learn and understand
  - Often safer than real applications, more reliable to "fail safe"

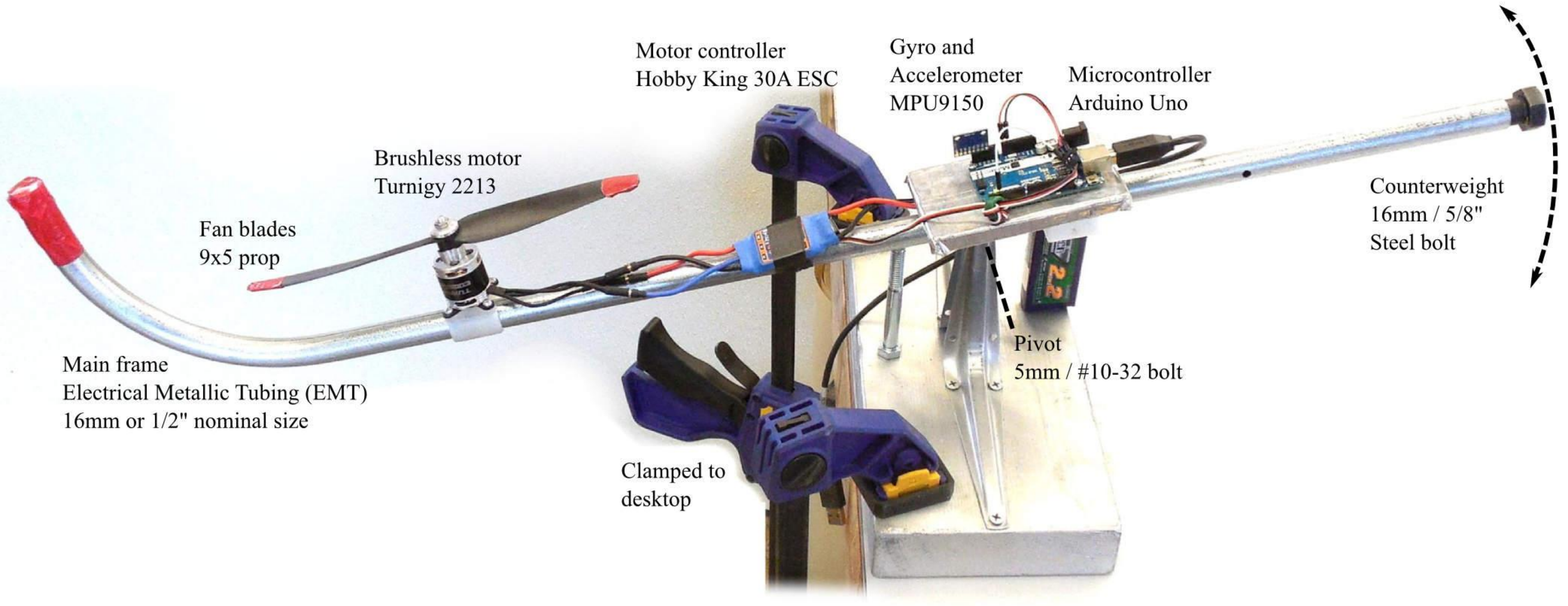
Cyber-Physical Systems (CPS) Education Needs

- **Unmanned Aerial Vehicles: a hard and important cyber-physical system**
- **Good opportunity for students to explore:**
  - **Sensors: accelerometer & gyro**
  - **Online realtime control**
  - **Force and torque**
- **UAVs are poor teaching tools!**
  - **Tend to crash and break**
  - **Short dynamical time (too fast)**
  - **Vibration requires filtering**

The Aero Beam: a UAV on a stick



- **Cannot crash**
- **Uses UAV brushless 3-phase motor and ESC**



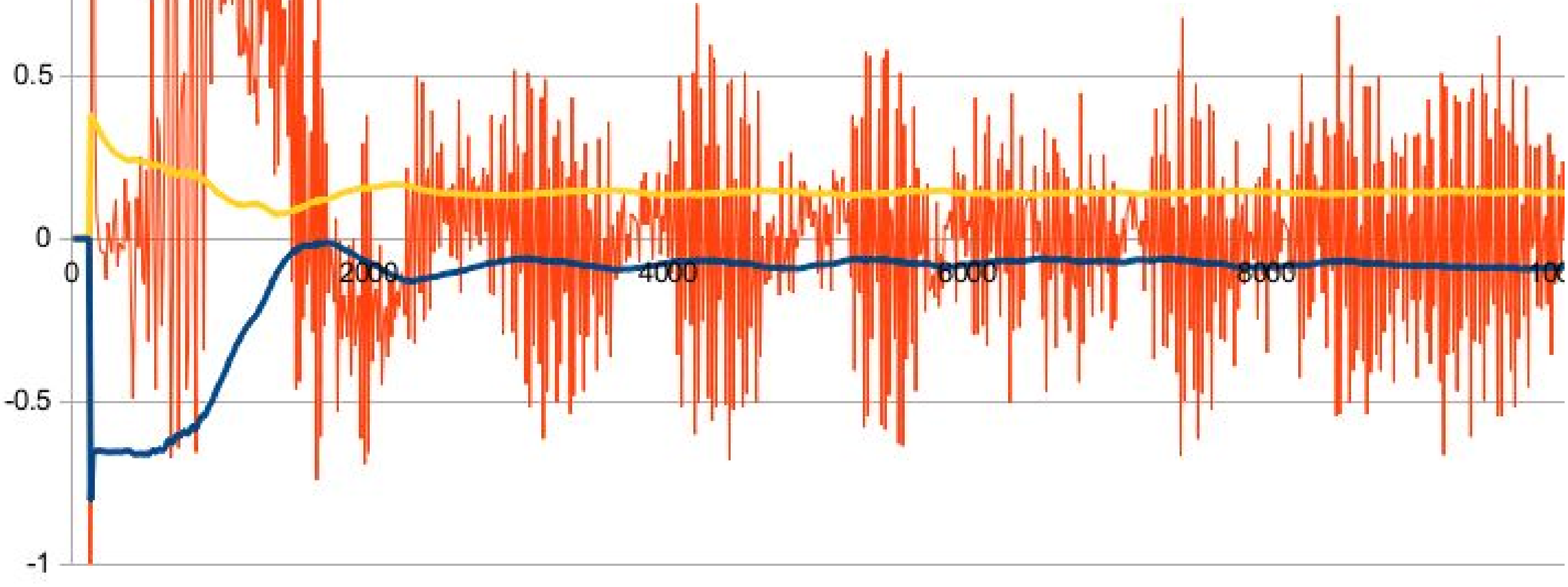
- **Simple, robust commodity parts, total cost under $100**
- **Accelerometer and gyro connected to a control Arduino & PC**

Control Scheme

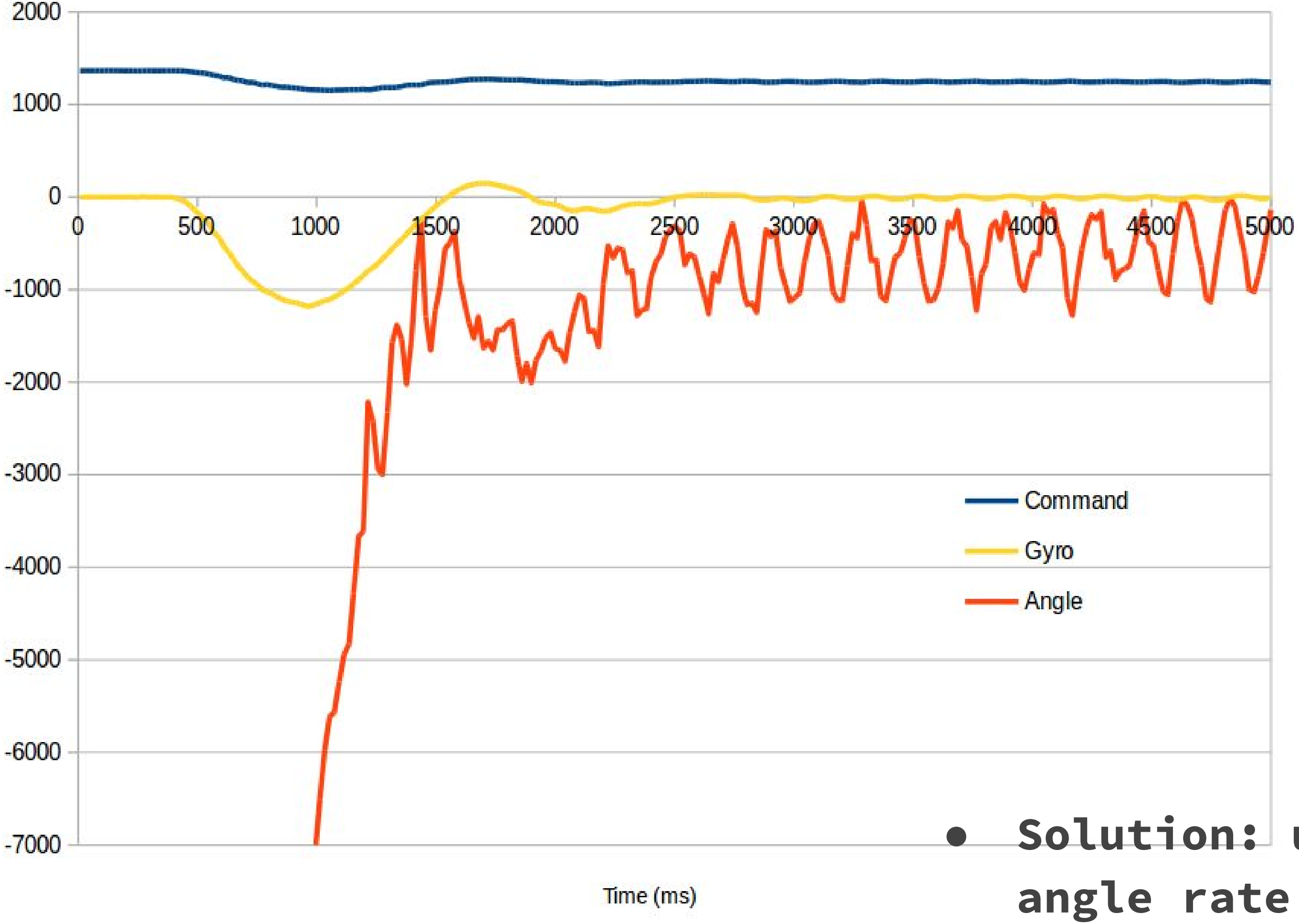
- **Simple application of PID control:**
  - **Proportional: reacts to angle error, to keep beam horizontal.**
  - **Derivative: negative feedback on angular rate, to damp oscillations.**
  - **Integral: reacts to cumulative error, to correct long-term average.**

```
motor  =  p_gain*err + d_gain*rate + i_gain*total + motor_idle
```

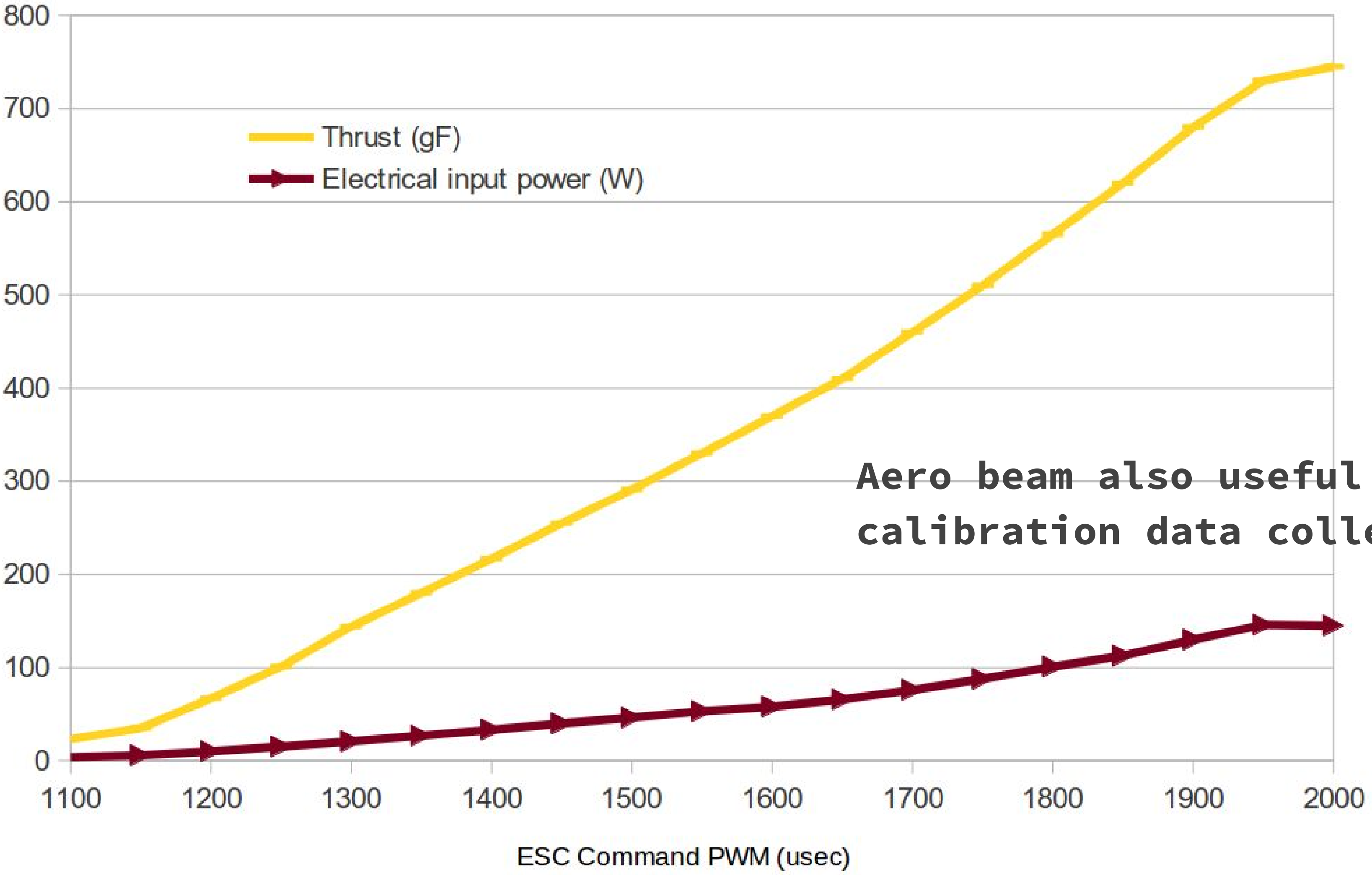
- **Read angle error estimate from accelerometer**



- **Challenge: vibration from the fan motor (yellow) adds noise to the accelerometer's angle estimate (blue)**
- **Because angle rate is derivative of angle, this noise makes the derivative term (orange) nearly useless**



- **Solution: use gyro to get angle rate estimate with less noise**

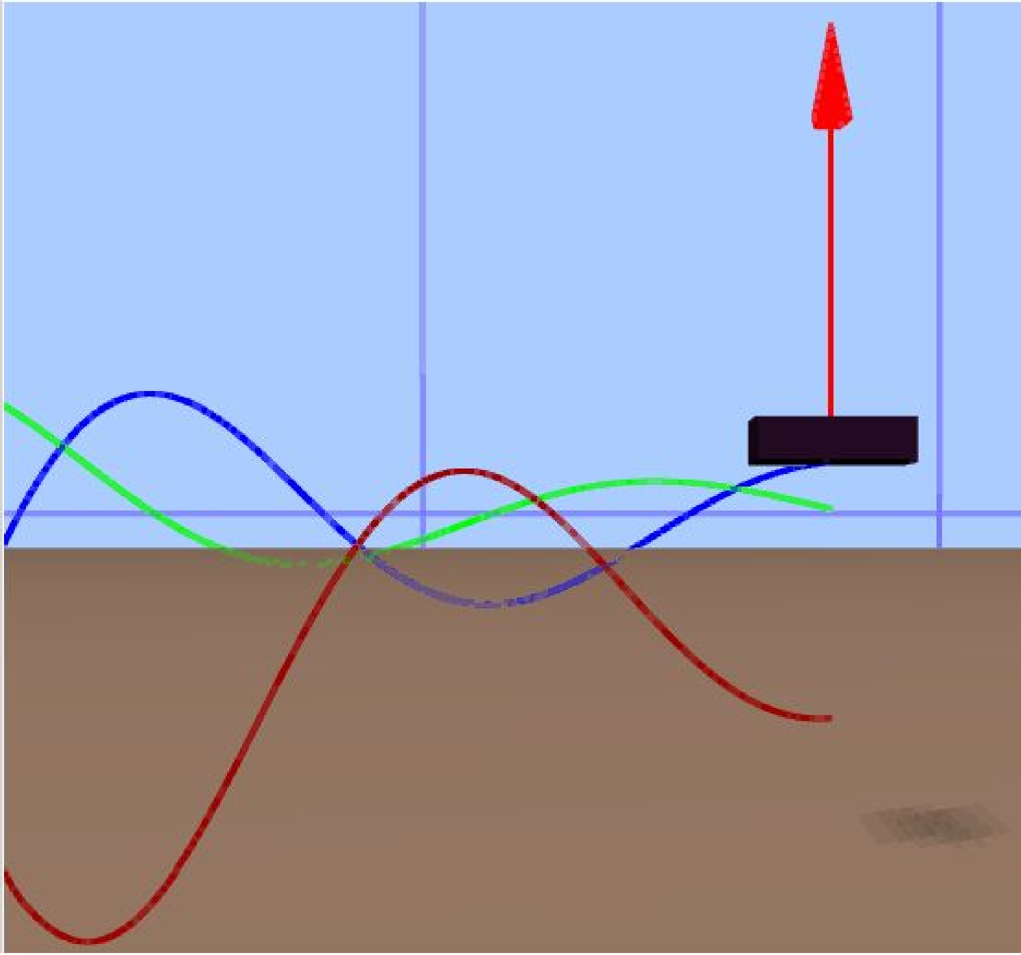


Aero beam also useful for calibration data collection

cyberalaska.cs.uaf.edu/uavsim/altitude.html

Loop Setup UI Save Stats

```
/* Manual keyboard control:
 Press i (more thrust) and k (less thrust).
 Or, uncomment and tune this one-line autopilot!
*/

uav.lift=-10.0*uav.error-2.0*uav.rate-0.5*uav.total;

/* Variables:
uav.lift: fan motor force, red
   Newtons (positive means up)

uav.error: altitude error, blue
   meters (positive means too high)

uav.rate: altitude rate, green
   meters/second (positive means climbing)

uav.total: total recent altitude errors
   meters (positive means usually too high)
*/

/* Simulate Physics */
uav.simulate_physics(lib.dt);
```



- **Web simulator:**

  no batteries needed!

Conclusions

- Testbeds are useful for teaching cyber-physical systems

- Aero beam useful for teaching control theory:
    - Closed-loop control, PID algorithm
    - Hands-on tuning
    - Scalable from primary school to master's level university work.

- Which of your problems needs a testbed?

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