AA 449
Final Milestone Report
Blimp Project

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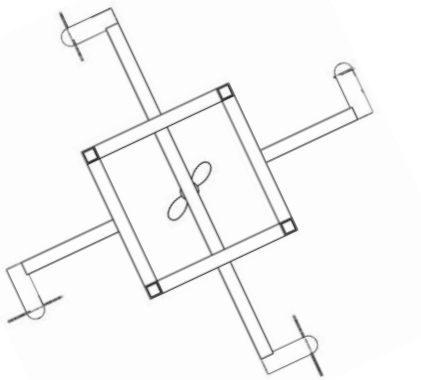
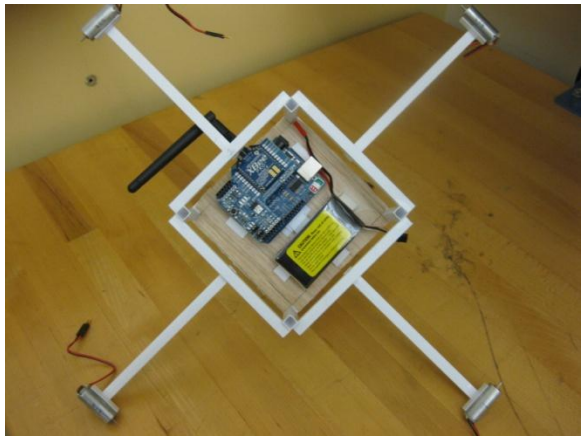
Project and Customer

- Distributed Space Systems Lab
  - Professor Mehran Mesbahi of AA
- Customer goals
  - Testbed for distributed control algorithms
  - Utilize DSSL camera sensor system
  - MATLAB implementation
  - Hardware available for future use by DSSL
- Blimp vehicle goals
  - Way point tracking
  - Coordinated tasks

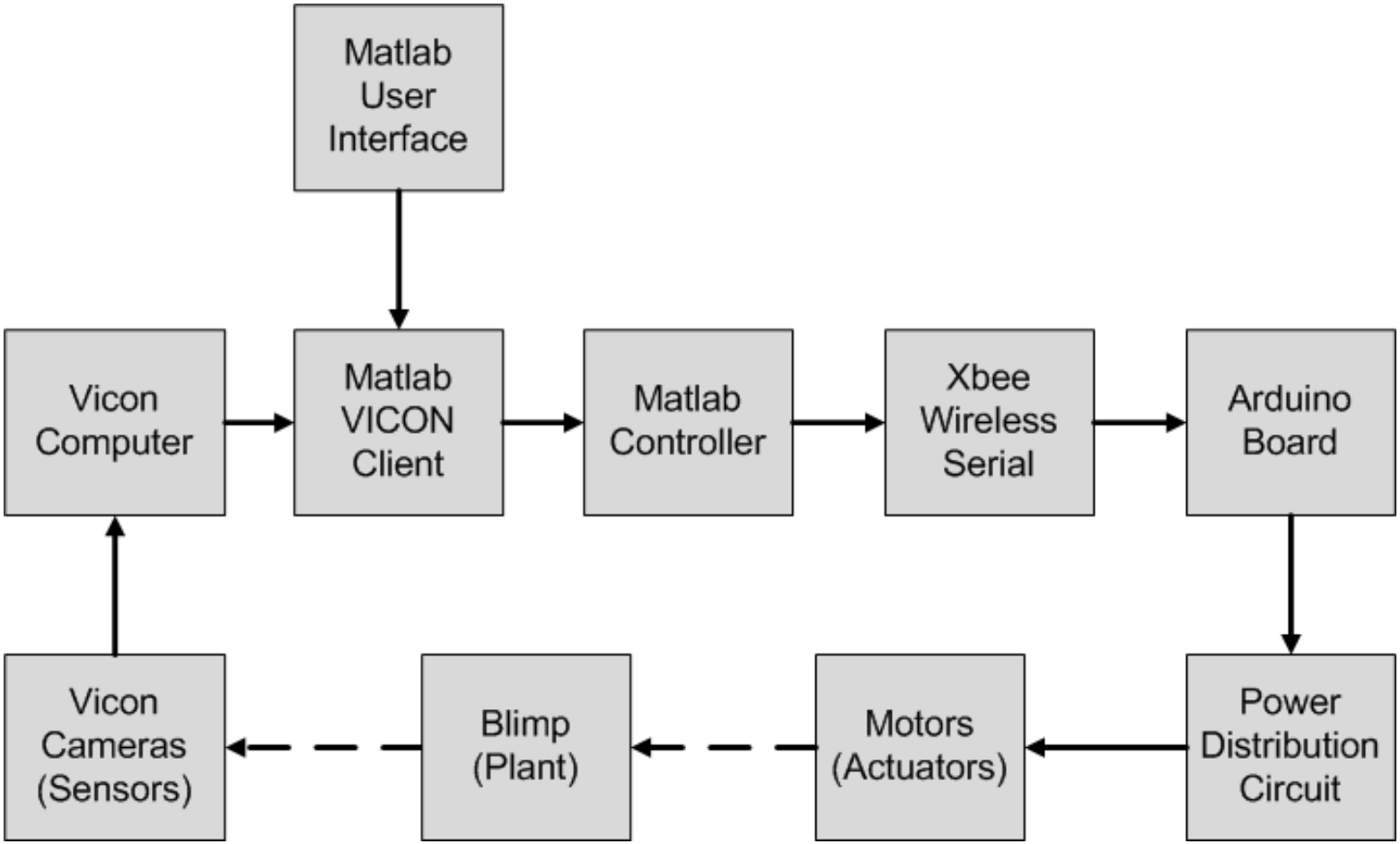
Blimp System and Performance Goals

- Helium balloon provides neutrally buoyant platform
- 5 DC motors placed to allow 3 DOF translation and yaw
- Performance goals
  - Negligible steady state error in position tracking
  - Cross camera space in 30 seconds
  - Rotate 180° in 30 seconds
  - Lead/Follow

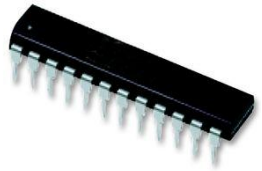




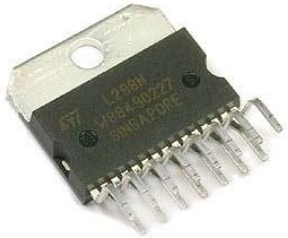
System Architecture



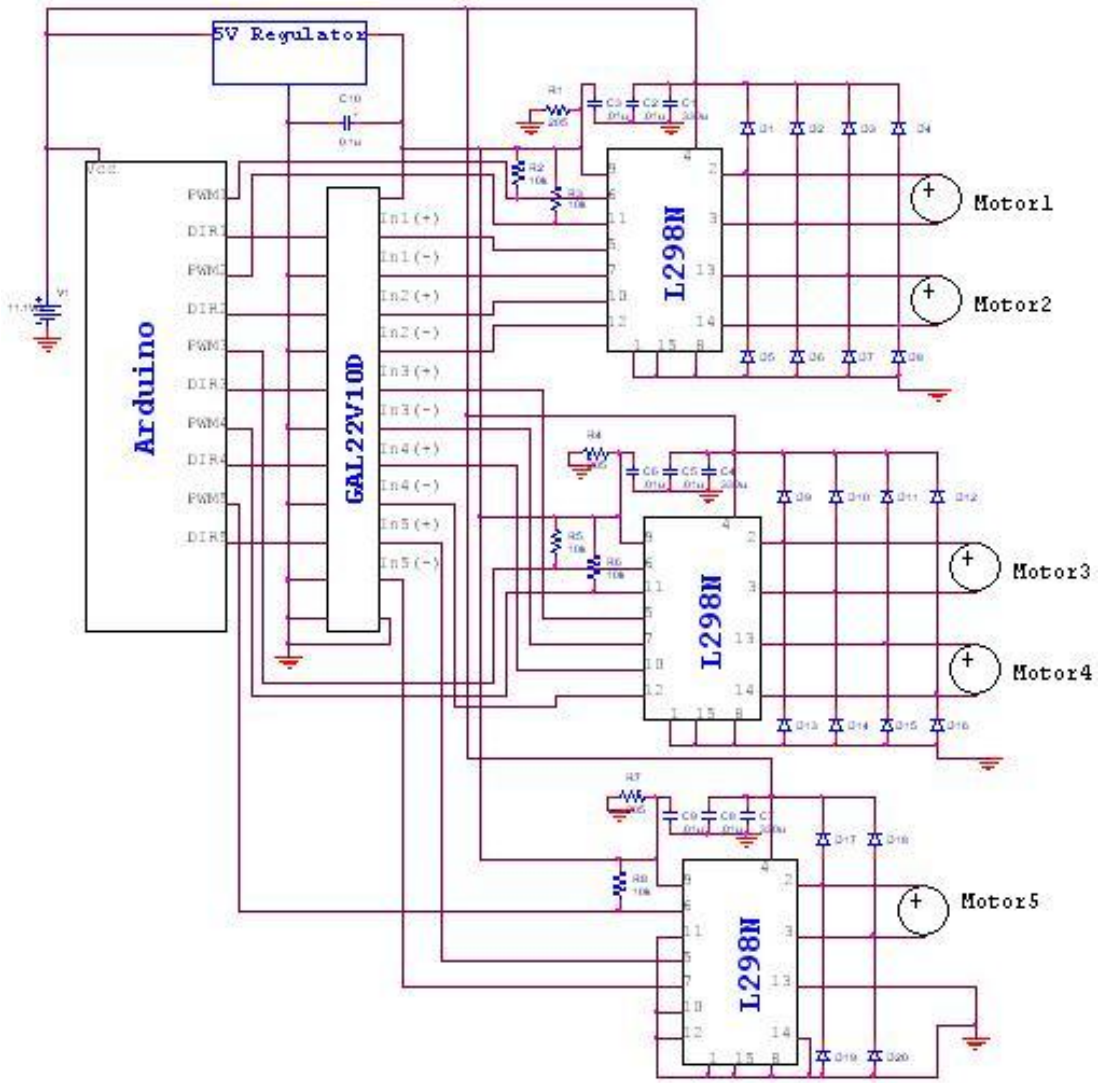
Hardware



- DSSL Vicon camera system
  - Infrared cameras sense reflective marker positions
- DC Motors
- Xbee wireless communication modules
- Arduino
  - ATMega 328P
- Power distribution circuit board
  - GAL chip
  - L298N dual H-bridge motor drivers
  - Voltage regulator



Circuit Schematic



Reference Frames and Equations of Motion

- Body-fixed reference frame moves and rotates with vehicle
  - Easier to formulate vehicle dynamics
- Inertial reference frame fixed in lab
  - Necessary for tracking/commanding position

$$\frac{d}{dt}\begin{bmatrix}\dot{x}_b\\ \dot{y}_b\\ \dot{z}_b\end{bmatrix} = \frac{1}{m}\vec{F}_b - \begin{bmatrix}\dot{\theta}_x\\ \dot{\theta}_y\\ \dot{\theta}_z\end{bmatrix} \times \begin{bmatrix}\dot{x}_b\\ \dot{y}_b\\ \dot{z}_b\end{bmatrix}$$

$$F_{x,b} = F_2 - F_4 - D\dot{x}_b{}^2$$

$$F_{y,b} = F_1 - F_3 - D\dot{y}_b{}^2$$

$$F_{z,b} = F_5 - D\dot{z}_b{}^2$$

$$\ddot{\theta}_{zb} = r_f(F_1 + F_2 + F_3 + F_4)$$

Linearized State Space Model

- Passively stable in pitch and roll
  - Control in 4 degrees of freedom
  - Controllable and observable
- Linearize about multiple operating points
  - Body frame velocities
  - Heading angle
- A matrix contains reference frame transformations and system dynamics
- B matrix contains actuator dynamics
- C matrix outputs position states

$$\vec{x} = \begin{bmatrix} x_r \\ y_r \\ z_r \\ \dot{x}_b \\ \dot{y}_b \\ \dot{z}_b \\ \theta_z \\ \dot{\theta}_{z,r} \end{bmatrix}$$

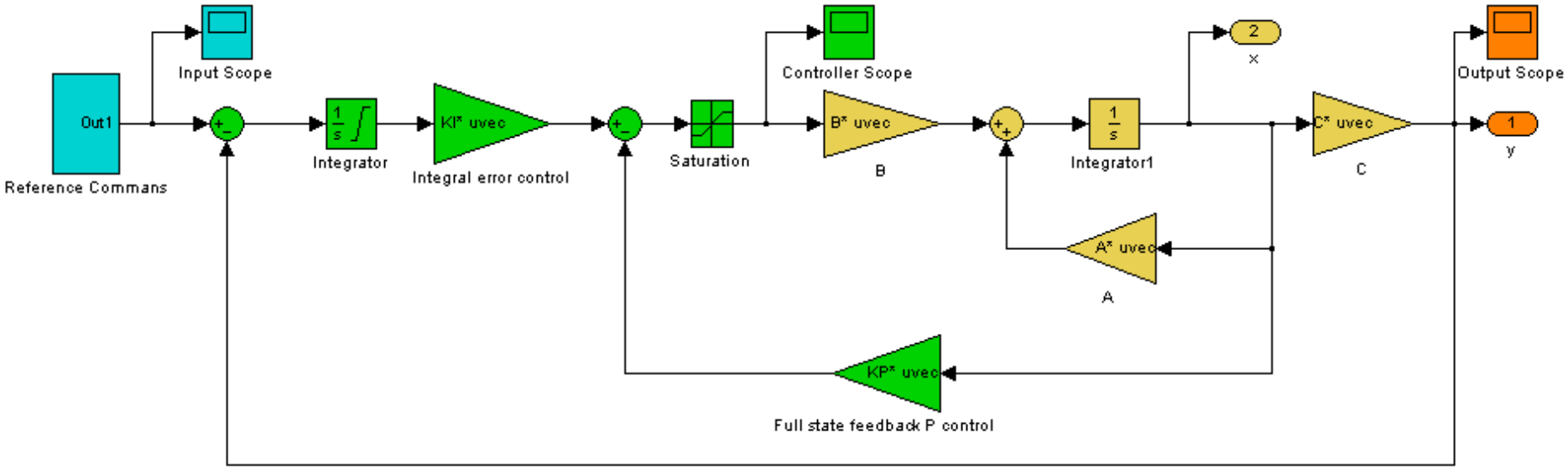
Control System Design

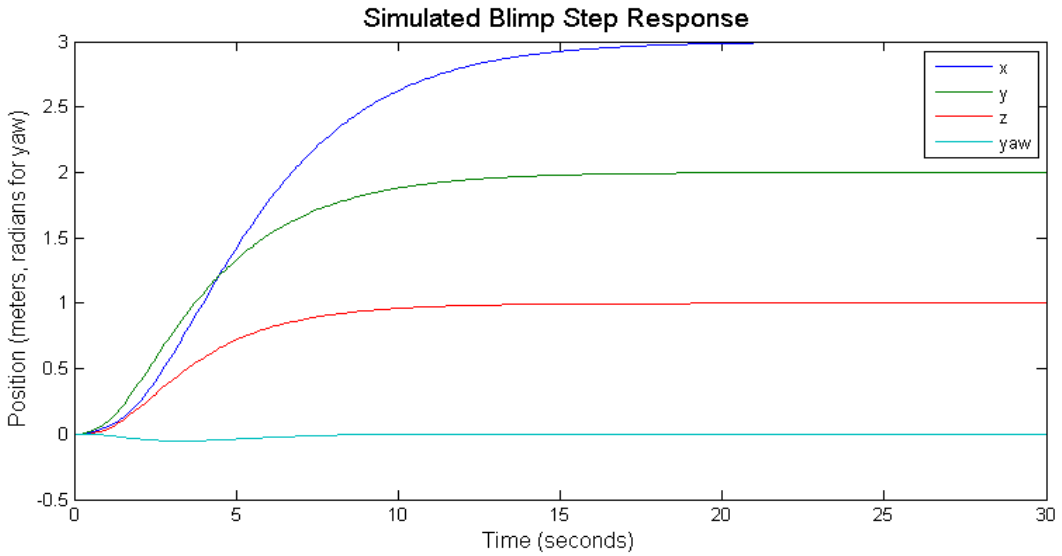
- Proportional control using full state feedback
  - Satisfy transient performance requirements
- Integral control of error between reference and output
  - Drive steady state error to zero
- Create augmented state equations using integral of error
- Pole placement using Matlab

$$\frac{d}{dt}\begin{bmatrix} x \\ z \end{bmatrix} = \begin{bmatrix} A - BK_p & -BK_I \\ -C & 0 \end{bmatrix}\begin{bmatrix} x \\ z \end{bmatrix} - \begin{bmatrix} 0 \\ B \end{bmatrix} r$$

$$A_{aug} = \begin{bmatrix} A & 0 \\ -C & 0 \end{bmatrix} - \begin{bmatrix} B \\ 0 \end{bmatrix}\begin{bmatrix} K_p & K_I \end{bmatrix}$$

Simulation


Out1
Reference Commans
Input Scope
Integrator
KI* uvec
Integral error control
Saturation
Controller Scope
B* uvec
B
Integrator1
2
x
C* uvec
C
Output Scope
1
y
A* uvec
A
KP* uvec
Full state feedback P control


Simulated Blimp Step Response
Position (meters, radians for yaw)
Time (seconds)
x
y
z
yaw
3
2.5
2
1.5
1
0.5
0
-0.5
0
5
10
15
20
25
30

Software Implementation

- Matlab client interfaces with Vicon
  - Parse marker position into C_g and heading
- Control law executed in Matlab
  - Full state feedback: Luenberger observer vs. differentiate inertial positions and transform
  - Bi-directional control implemented with logic
- GUI controls command position
- Arduino code interprets serial data and outputs to power distribution circuit

Flight Test!

Lessons Learned

- Transforming between reference frames can be complicated
- Balloons are fragile
- Neutral buoyancy is tricky
  - Air conditioning units are the enemy

Resources

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