Design and Implementation of

The JAviator Quadrotor

an Aerial Software Testbed

PhD Defense

Rainer Trummer
Department of Computer Sciences
University of Salzburg, Austria

May 27, 2011

Computational
Systems Group

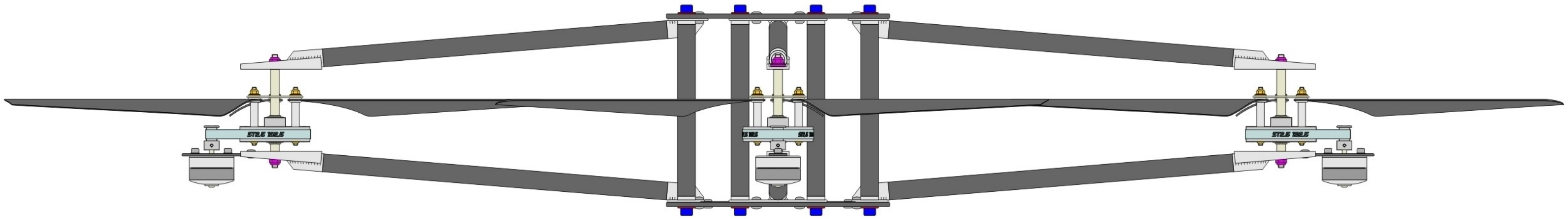
Presentation Outline

- Introduction
- Platform Development
- Control System Design
- Software Architecture
- Conclusions

Introduction – *State of the Art*

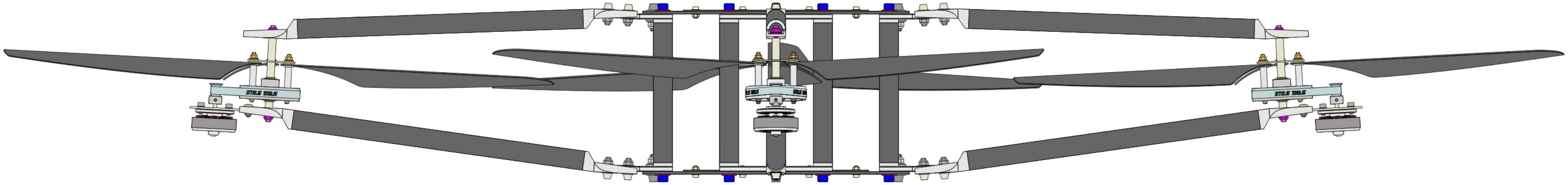
- Platform Development
  - Filigree airframes that seldom provide satisfactory integrity
  - Propulsion systems that seldom support notable payloads
- Control System Design
  - Precise indoor navigation only achieved with vision systems
  - Often computationally intensive pose estimation algorithms
- Software Architecture
  - Mostly event-triggered and tuned to comprising equipment
  - Temporal behavior is not preserved on different hardware

Introduction – *JAviator Aircraft*



- Jan 2006 – Aug 2007: ***JAviator V1***
  - Entirely hand-fabricated CFC, AL, and TI components
  - Total diameter (over spinning rotors): 1.1 m
  - Empty weight (including all avionics): 1.9 kg

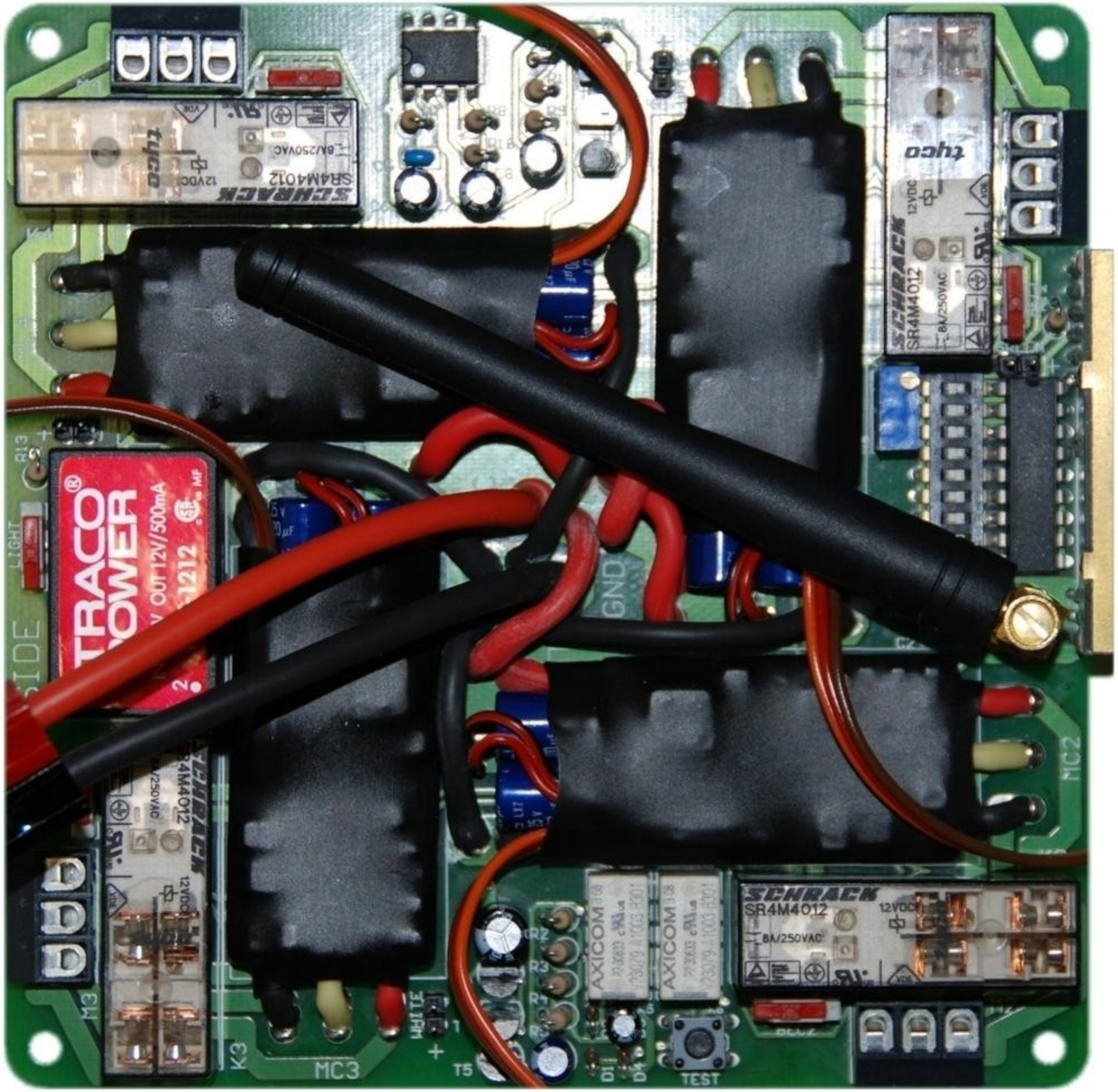
Introduction – *JAviator Aircraft*

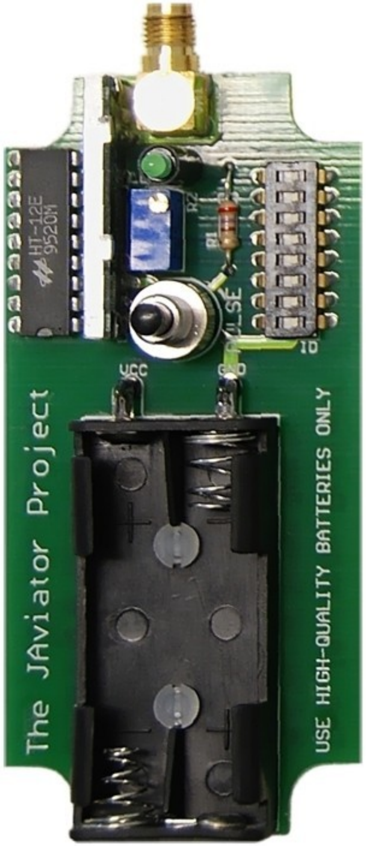


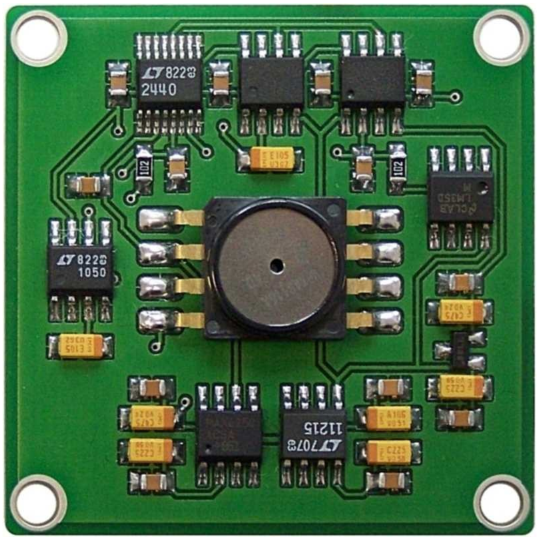
- Since February 2007: ***JAviator V2***
  - CNC-fabricated, flow-jet-, and laser-cut components
  - Total diameter (over spinning rotors): 1.3 m
  - Empty weight (including all avionics): 2.2 kg

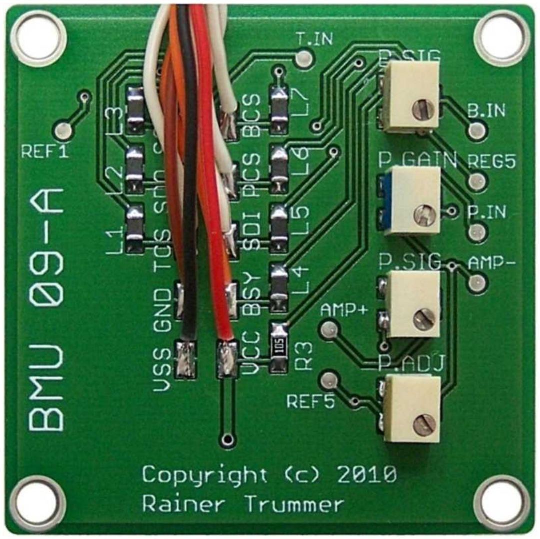
- Maximum flight endurance w/o payload: 38 min
- Maximum propulsion system capacity: 5.4 kg

Introduction – *JAviator Avionics*

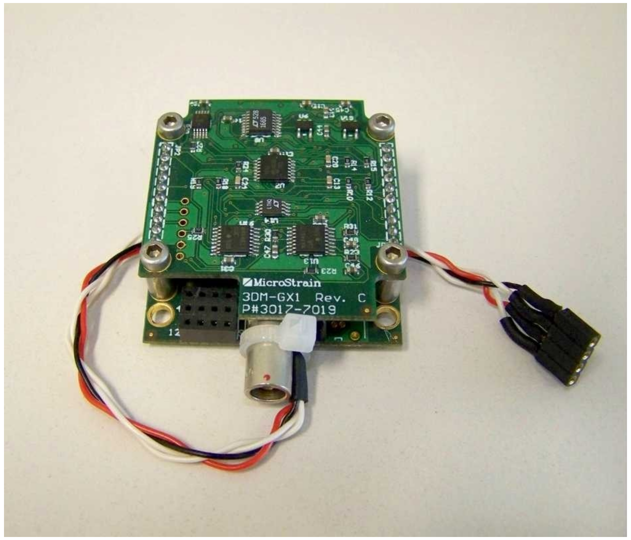


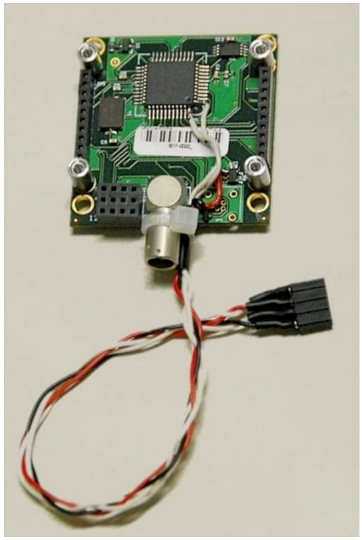


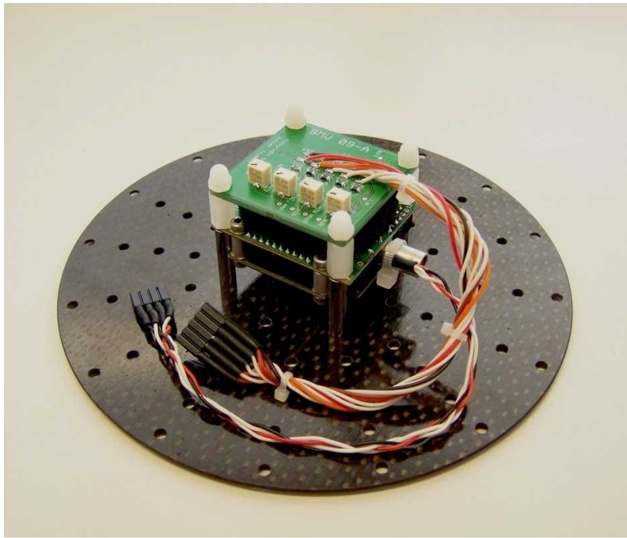


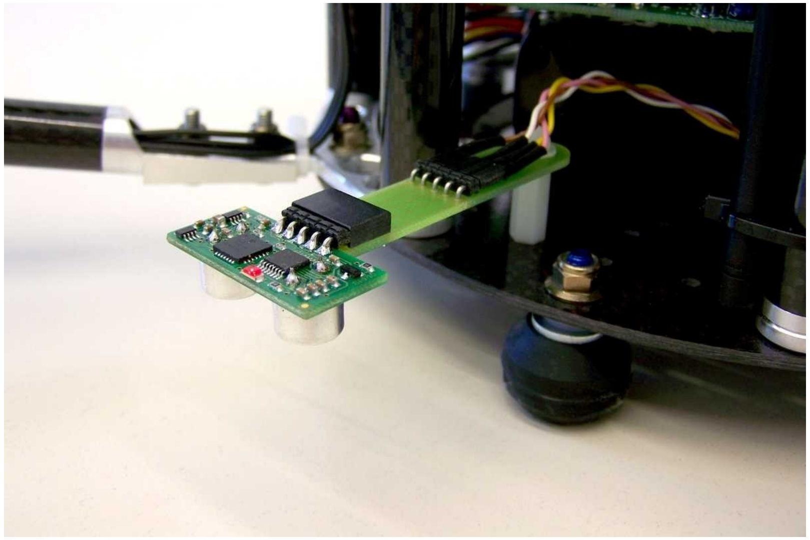

T.IN
B.IN
P.GAIN
REG5
P.IN
P.SIG
AMP-
AMP+
P.ADJ
REF5
REF1
BMU 09-A
Copyright (c) 2010
Rainer Trummer

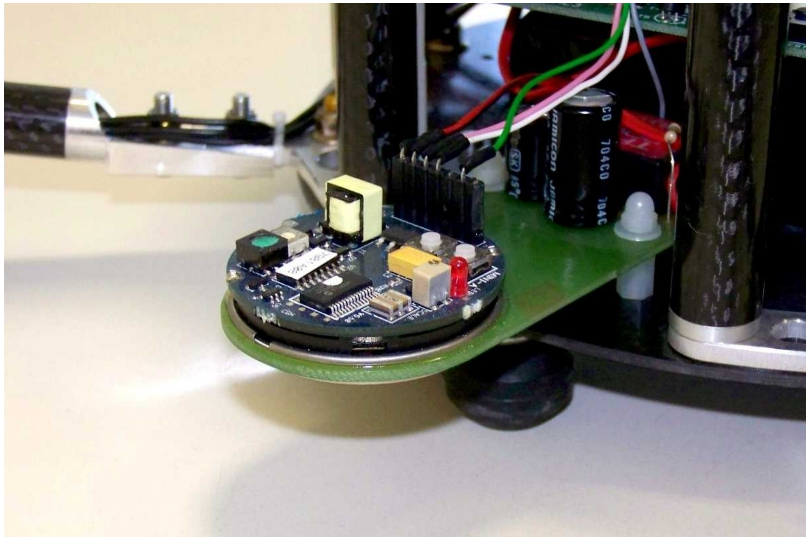
Introduction – *JAviator Avionics*



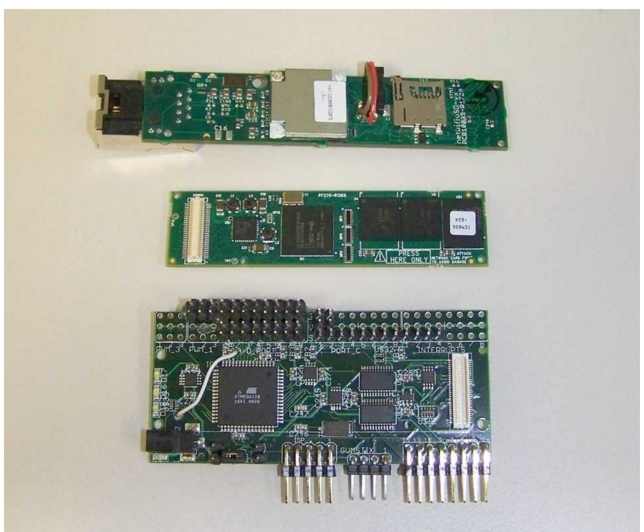


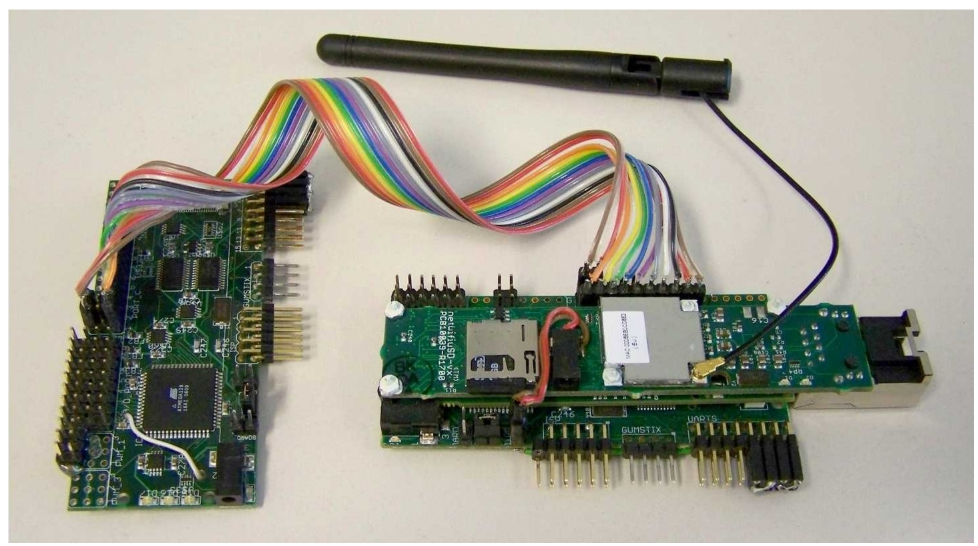




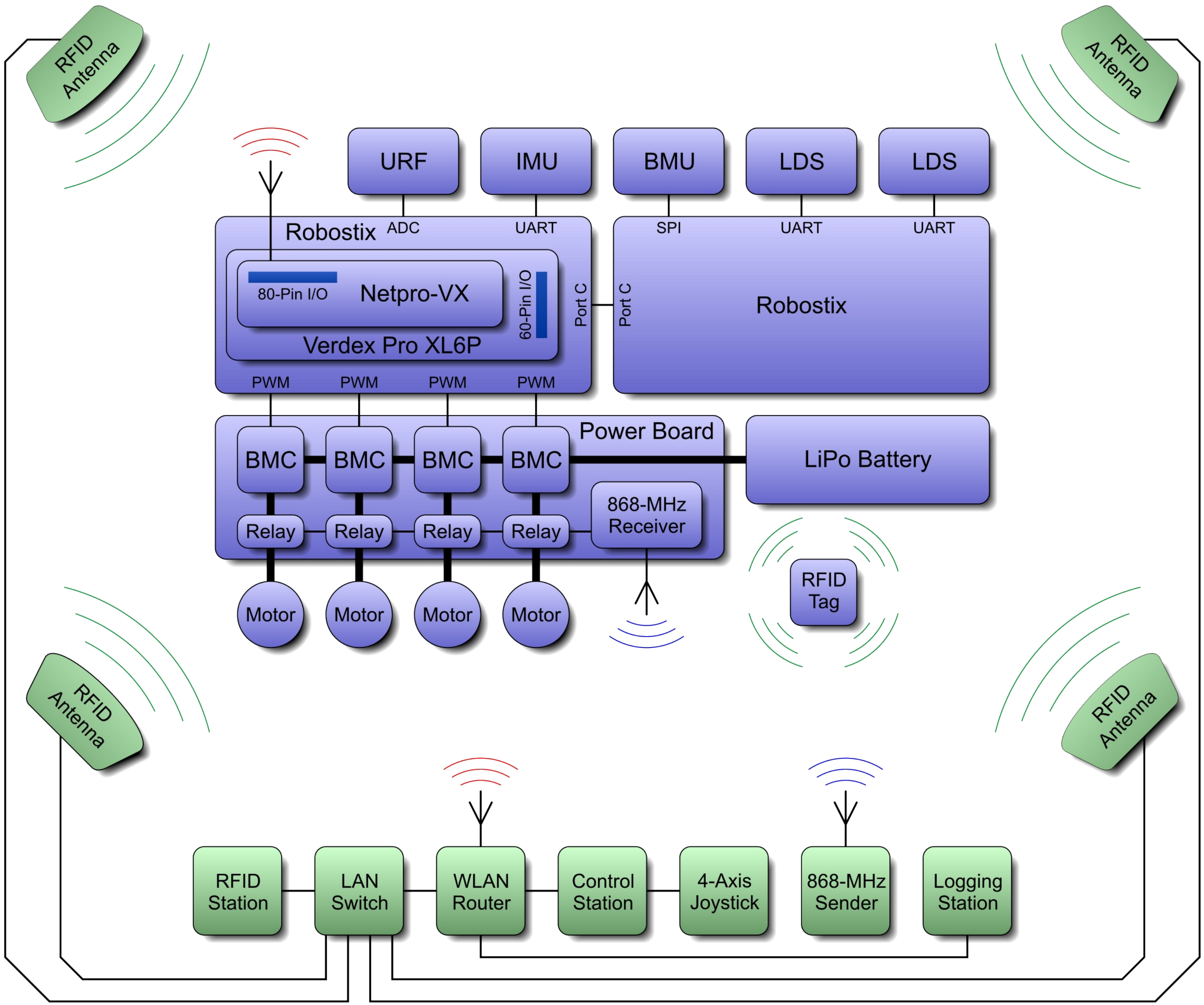


Introduction – *JAviator Avionics*





Introduction – *JAviator Computer System*



Introduction – *JAviator V2 In Flight*

Flying at a height of 3 m and hovering at a height of 1.5 m

Hovering inside a classroom and flying inside a corridor

Introduction – *Outdoor Flight Experiments*

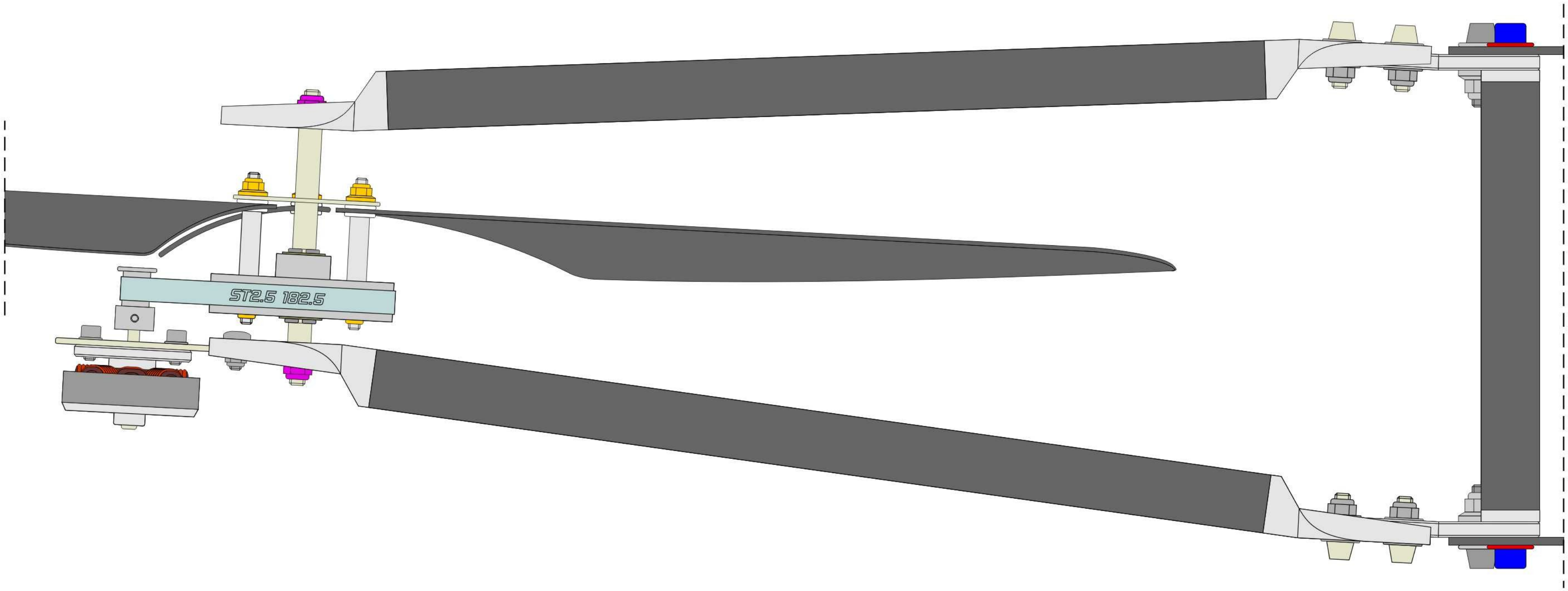
Platform Development – *Challenges*

How to achieve a high degree of …

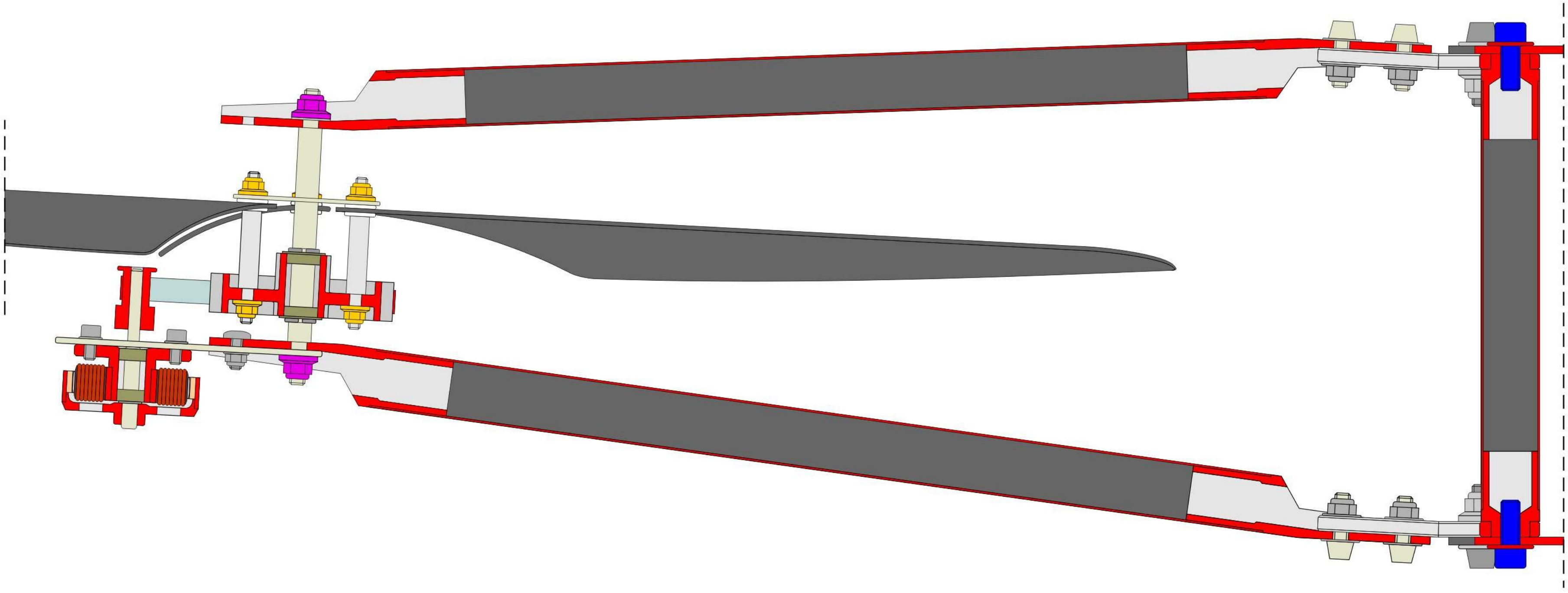
- Mechanical Integrity
- Payload Capacity
- Reproducibility

?

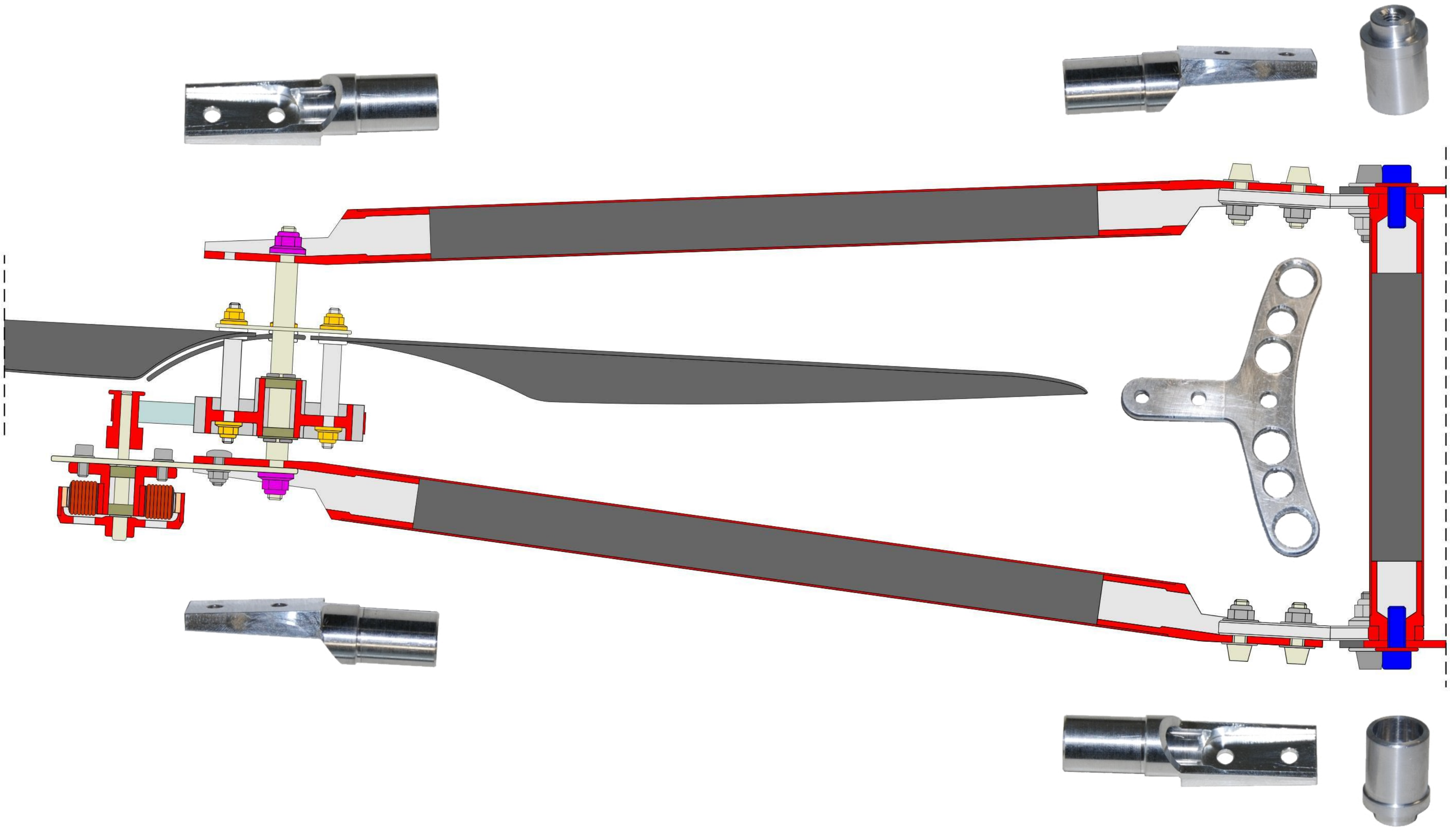
Platform Development – *Airframe Construction*



Platform Development – *Airframe Construction*



Platform Development – *Airframe Construction*

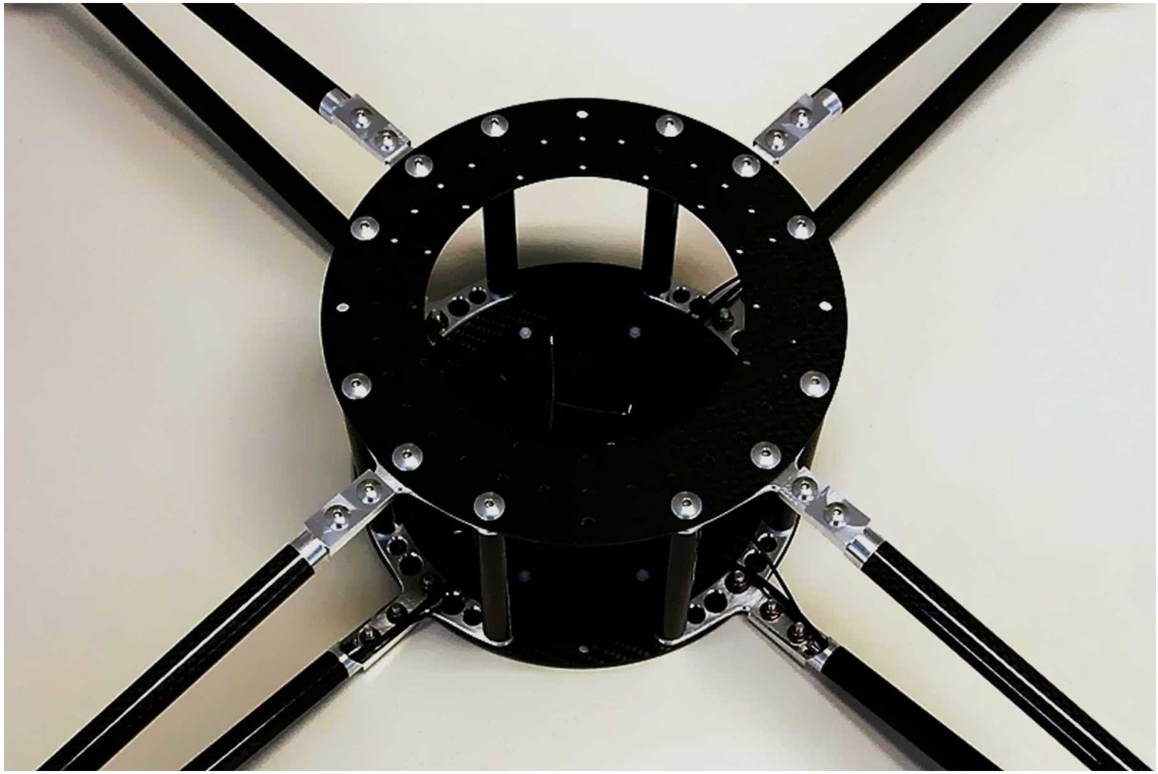


Platform Development – *Airframe Construction*

Platform Development – *Airframe Construction*

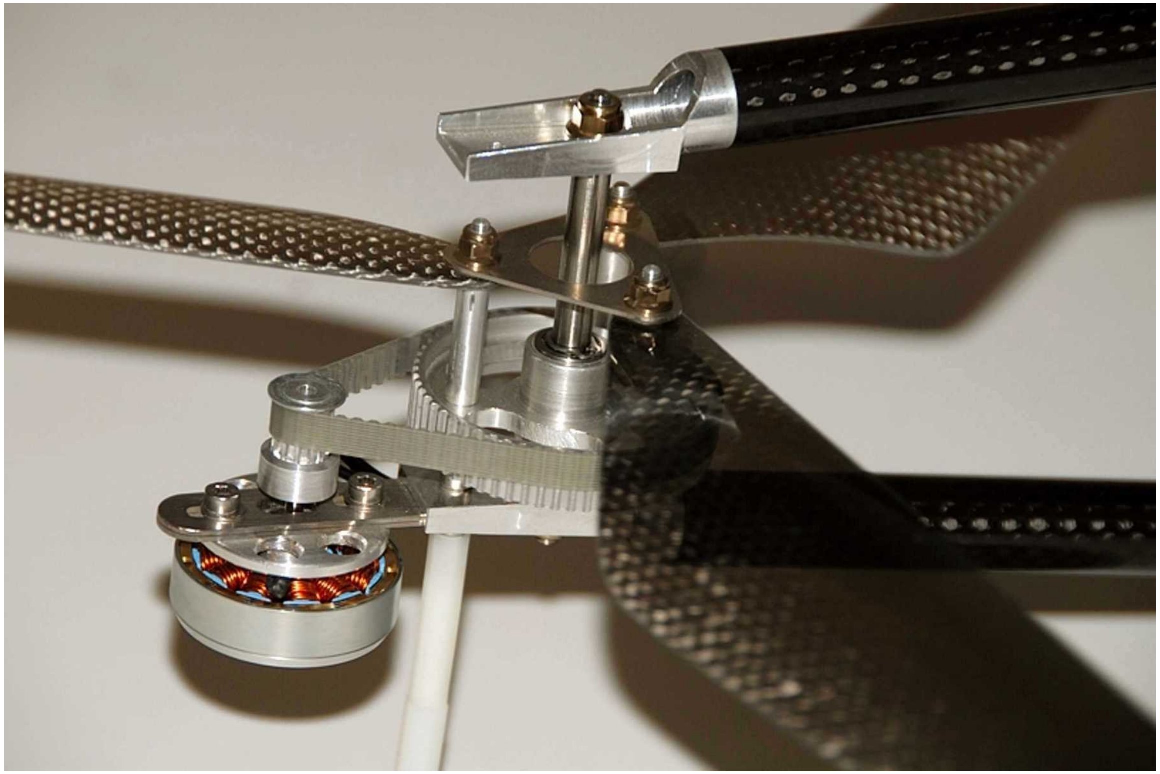
Platform Development – *Airframe Construction*

Platform Development – *Airframe Construction*



Platform Development – *Airframe Construction*

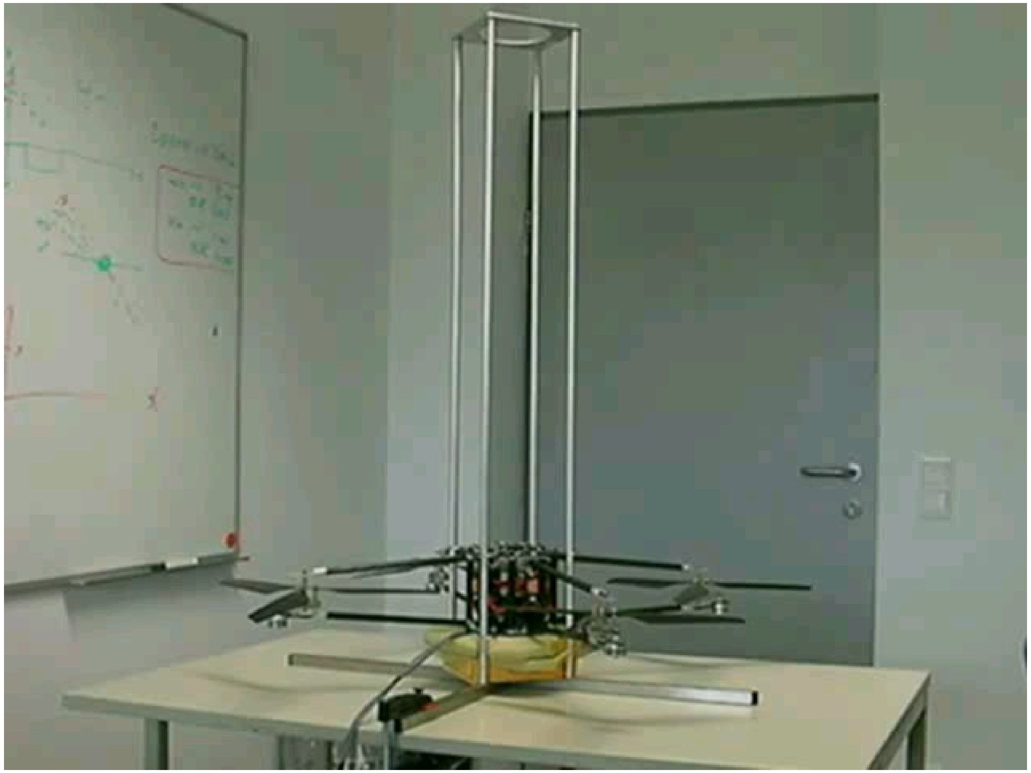
Platform Development – *Airframe Construction*



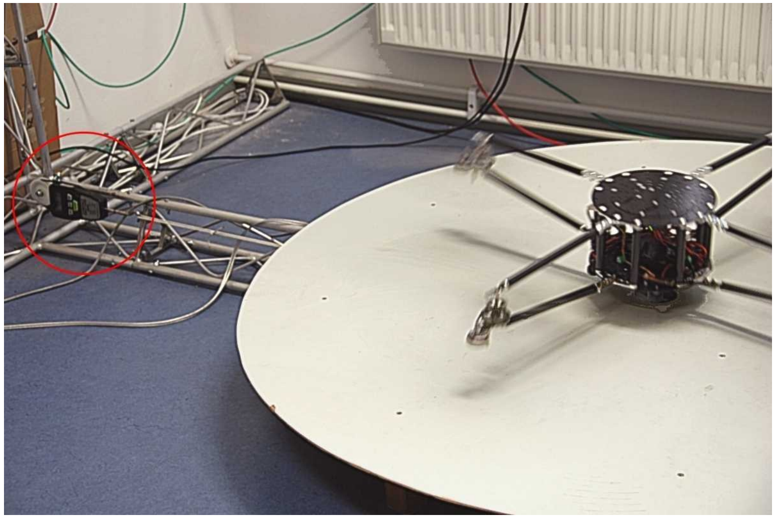
Platform Development – *Maximum Power*

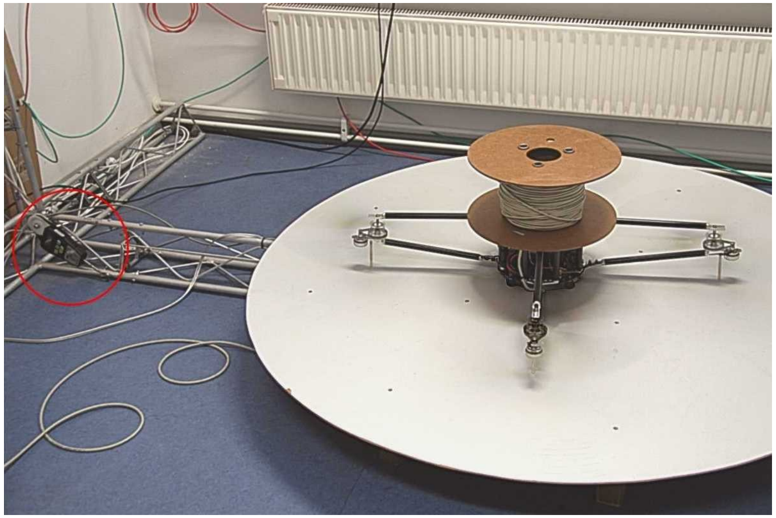
Platform Development – *Maximum Thrust*

Platform Development – *Acceleration Test*



Platform Development – *JAviator V2 Capability*





Lifting Capacities

Experiment	Gearing	Thrust (%)	Force (kg)
Craft without payload	1:6	43/54	2.2
Craft plus lifting 2.4/1.3 kg	1:6	100	4.6/3.5
Craft without payload	1:5	38/48	2.2
Craft plus lifting 3.2/1.9 kg	1:5	100	5.4/4.1

Battery Service Times

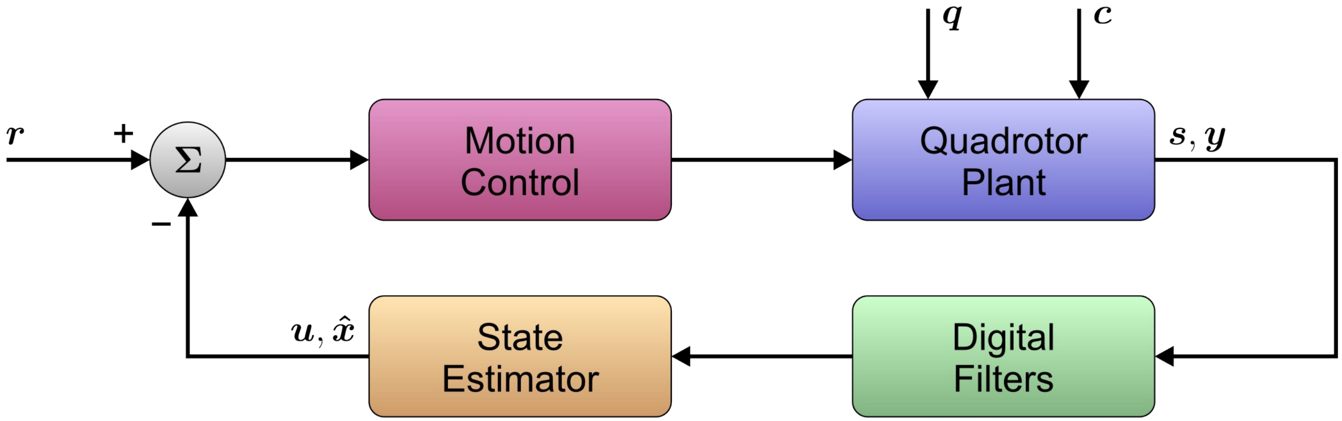
Experiment	Gearing	Thrust (%)	Time (min)
Craft without payload	1:6	43/54	37/28
Craft plus lifting 2.4 kg	1:6	100	11
Craft without payload	1:5	38/48	39/29
Craft plus lifting 3.2 kg	1:5	100	8

Control System Design – *Challenges*

How to achieve a high degree of …

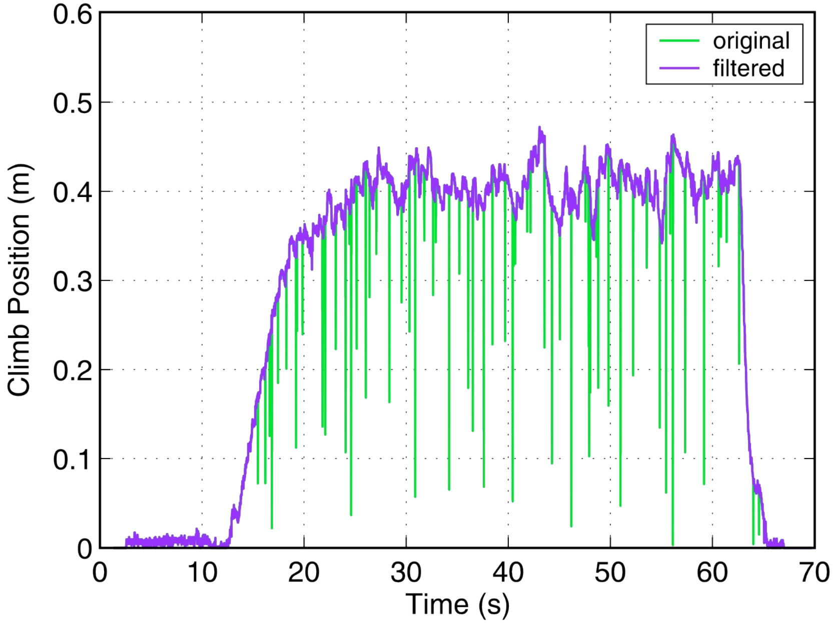
- Controllability
- Maneuverability
- Flight Autonomy

?

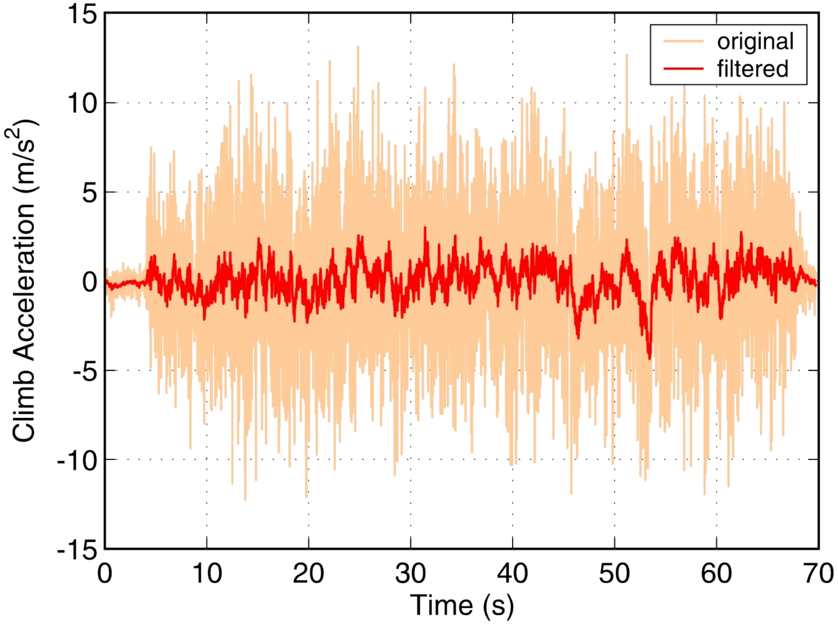


- State-Space-based Linear Feedback Control
  - Quadrotor Plant: samples inertial and positional data
  - Digital Filters: reject outliers and improve noisy data
  - State Estimator: computes EKF-based state estimates
  - Motion Control: generates PIDD-based motor signals

Control System Design – *Digital Filtering*

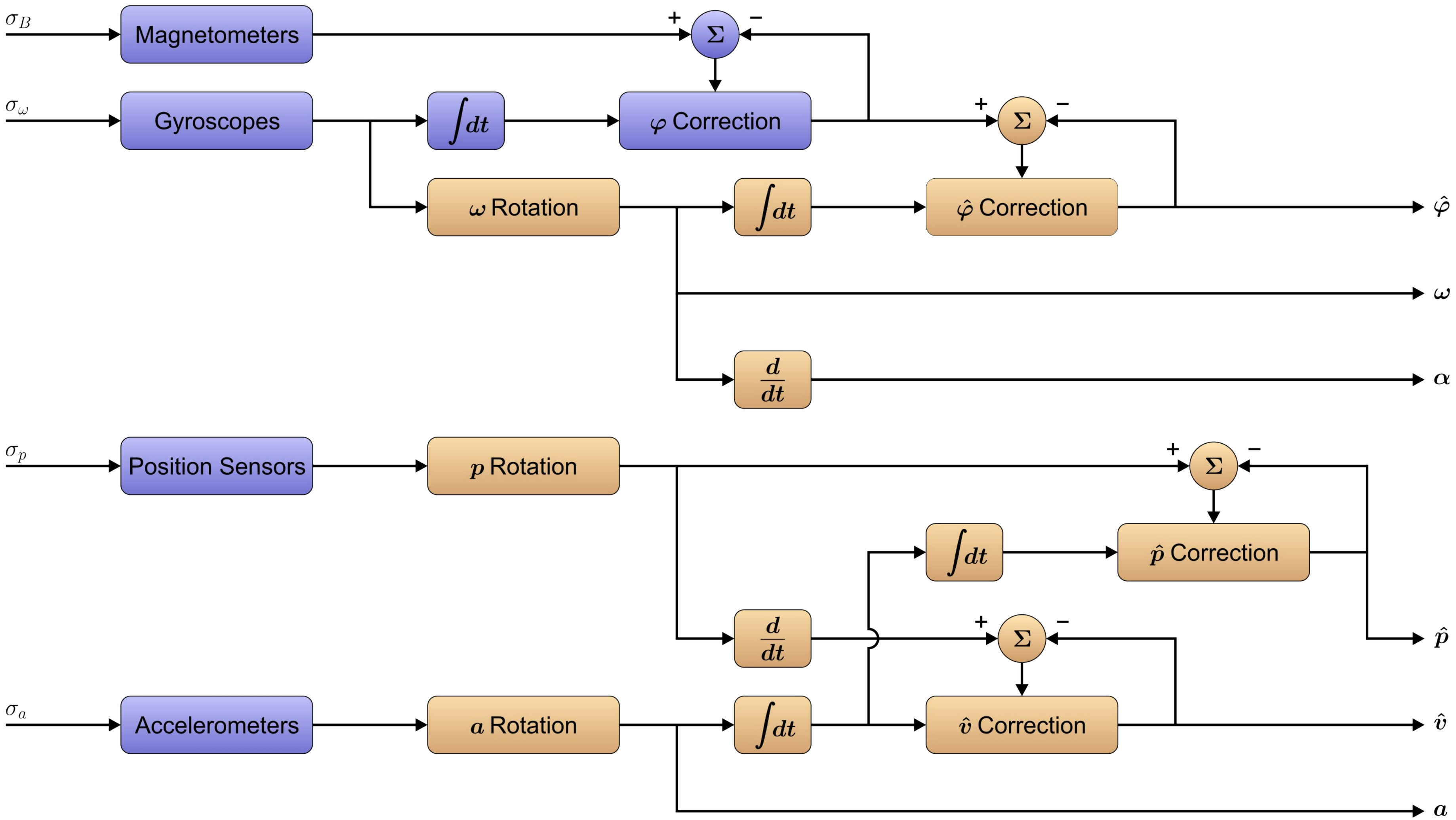


Differential Threshold outlier filter applied to climb-position data

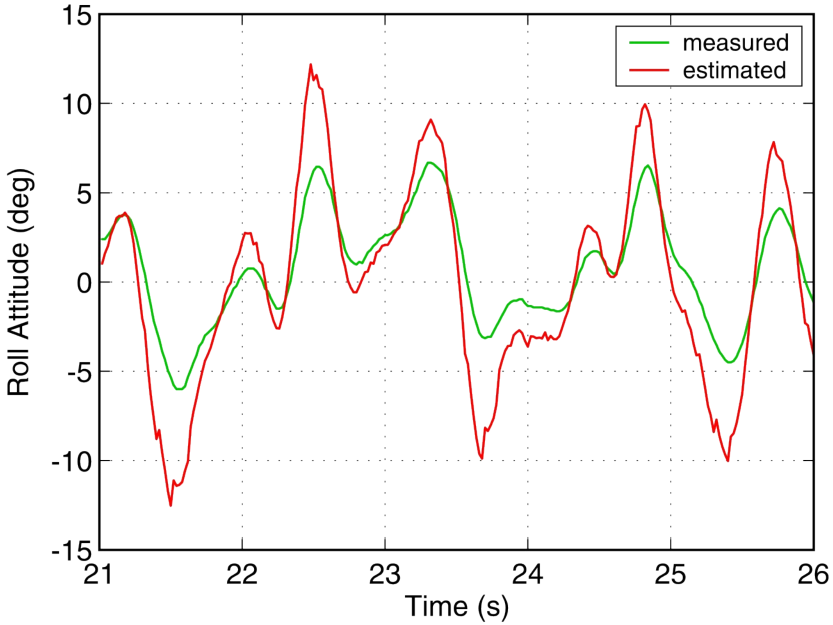


Infinite Impulse Response low-pass filter applied to climb-acceleration data

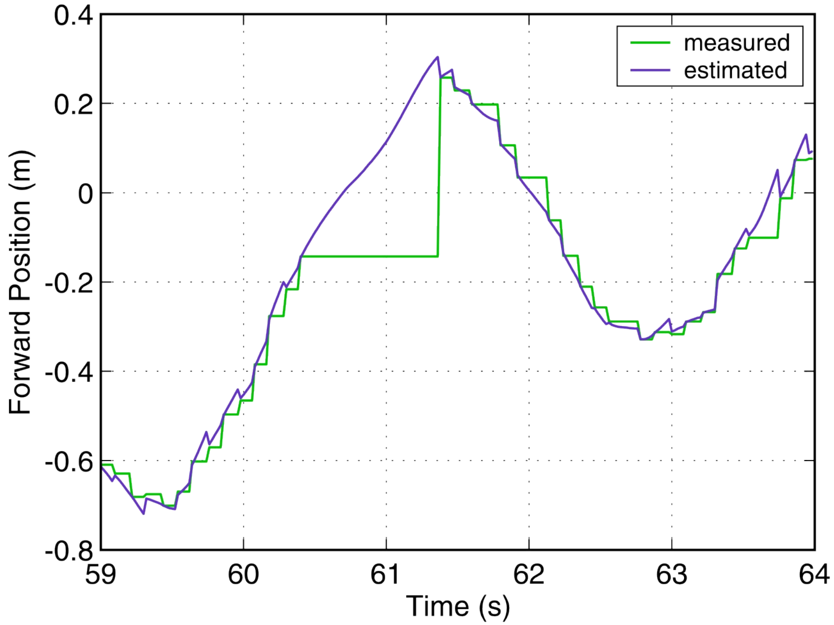
Control System Design – *State Estimation Model*



Control System Design – *EKF Performance*

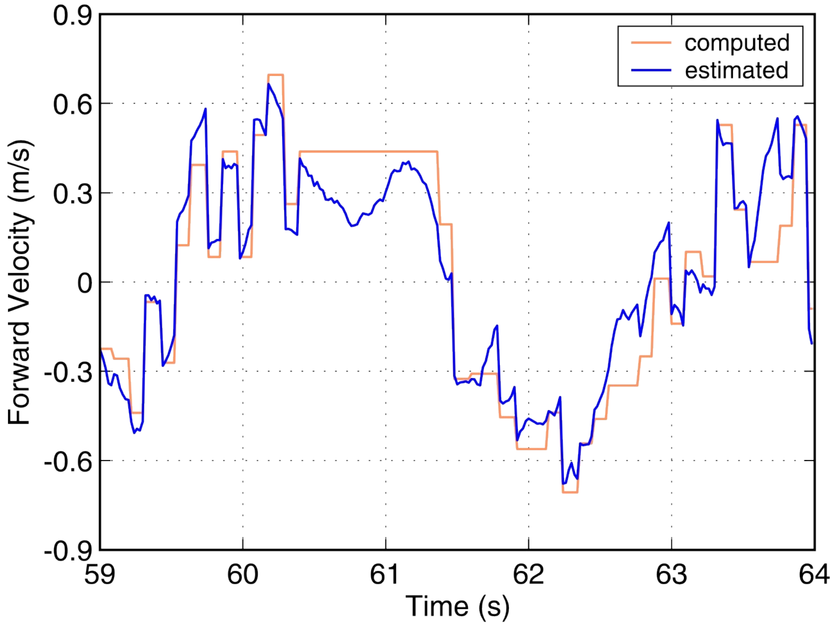


Attitude EKF provided with periodic angular-velocity measurements and ***synchronous*** attitude observations

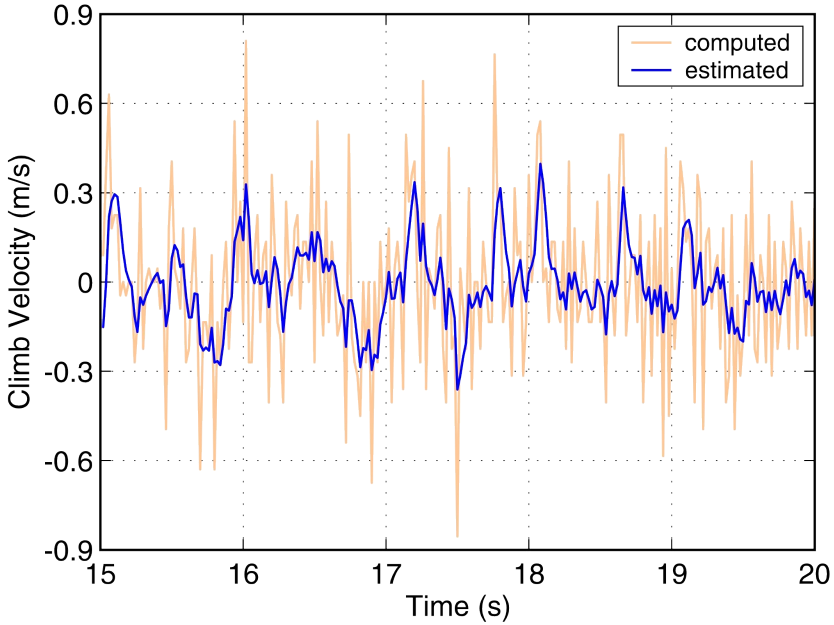


Position EKF provided with periodic acceleration measurements and ***asynchronous*** position observations

Control System Design – *EKF Performance*

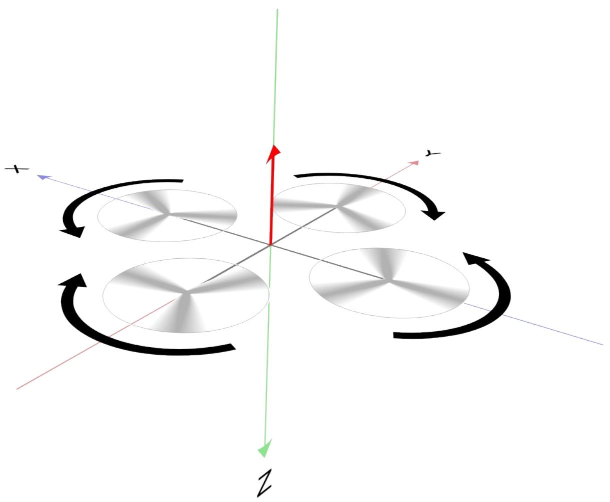


Velocity EKF provided with periodic acceleration measurements and ***asynchronous*** velocity feedback

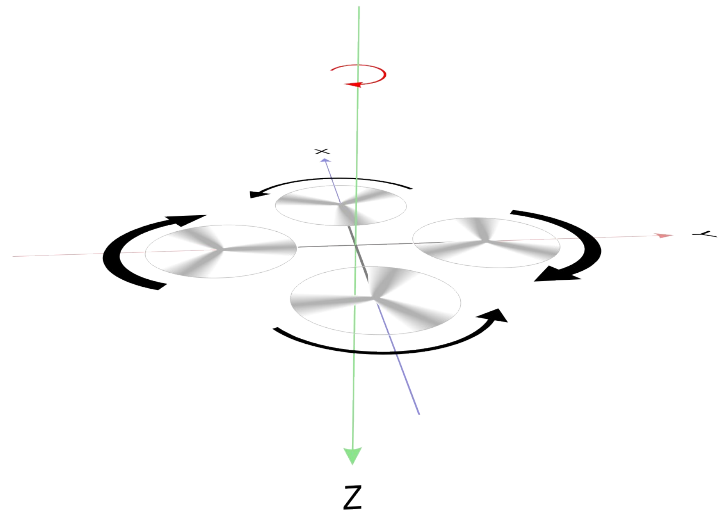


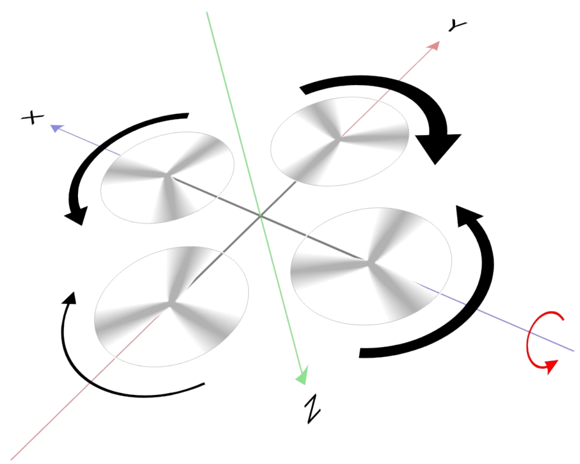
Velocity EKF provided with periodic acceleration measurements and ***synchronous*** velocity feedback

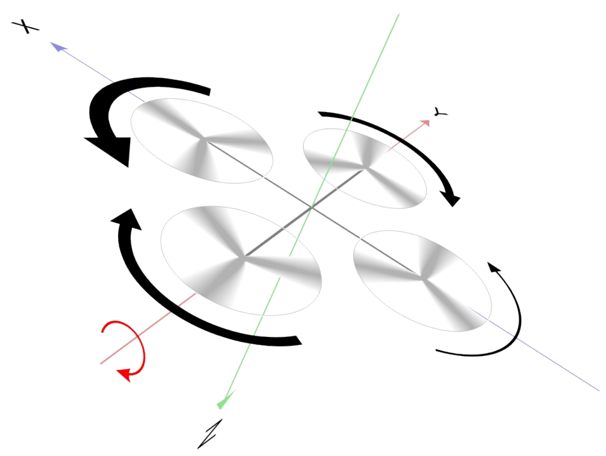
Climb



Yaw



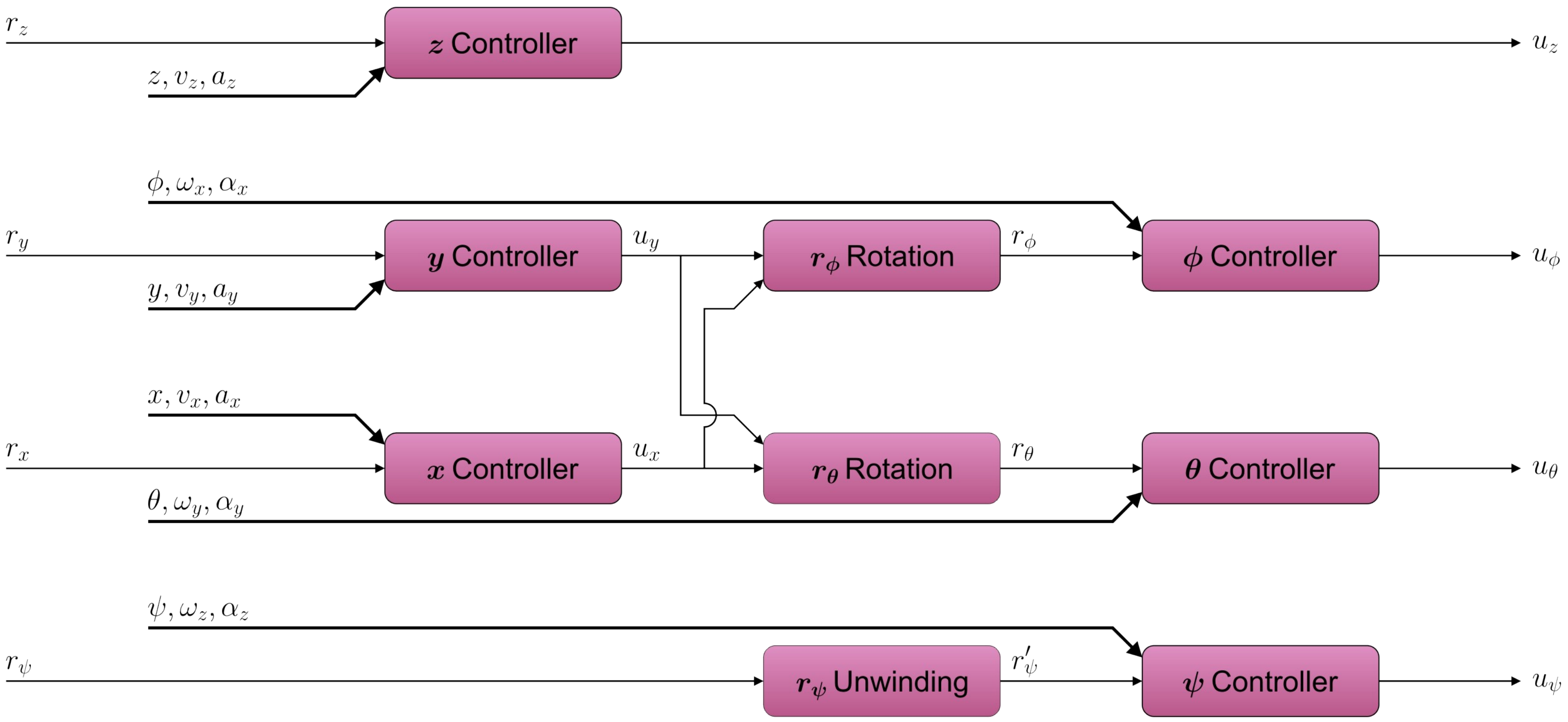




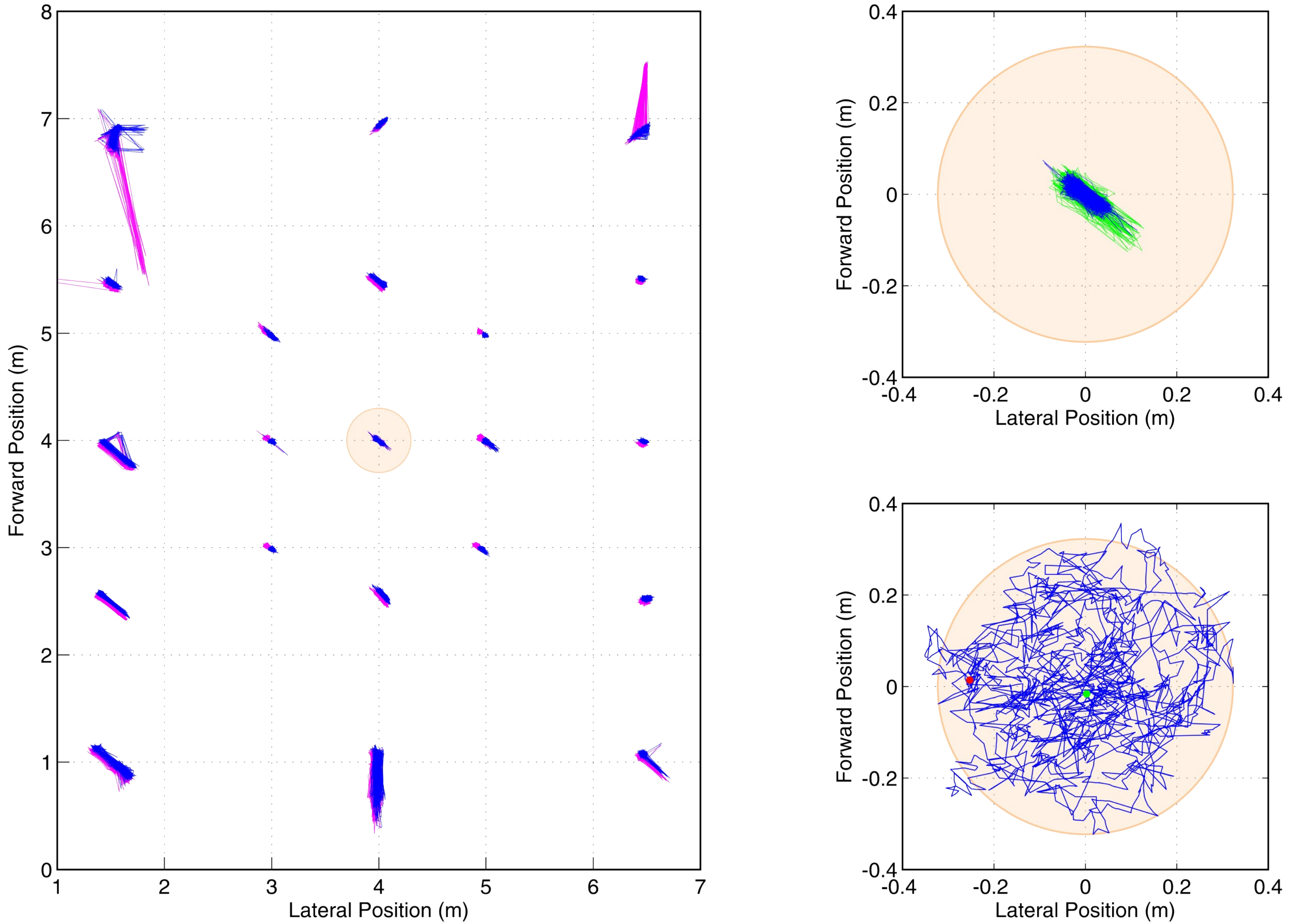
Roll

Pitch

Control System Design – *Motion Control Model*

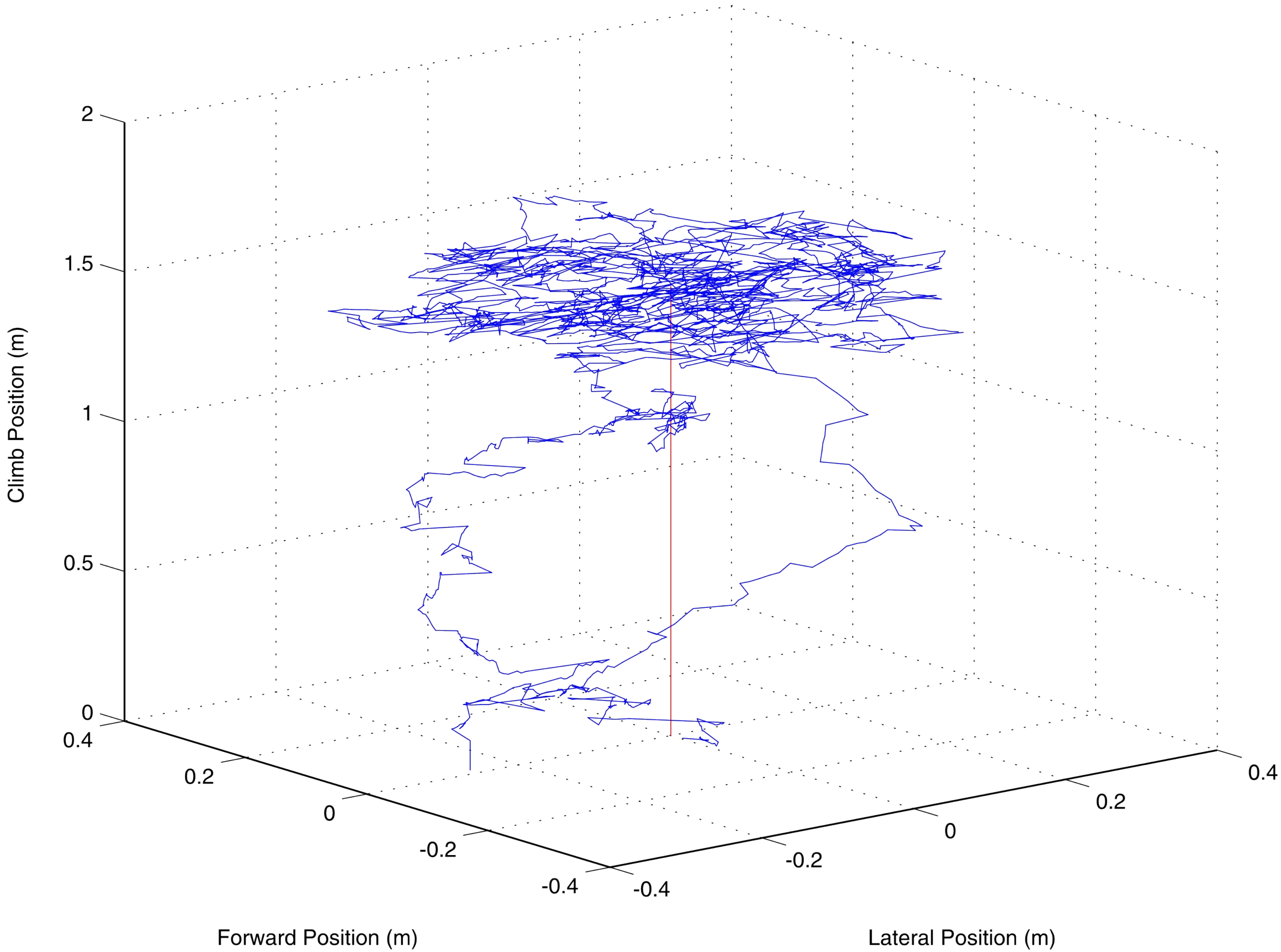


Control System Design – *Position Flight Control*



RFID accuracy (left), center point during lift-off (top right), and position-hold flight (bottom right)

Control System Design – *Position Flight Control*



Previous position-hold flight in 3D visualization

Control System Design – *Manual Hover*

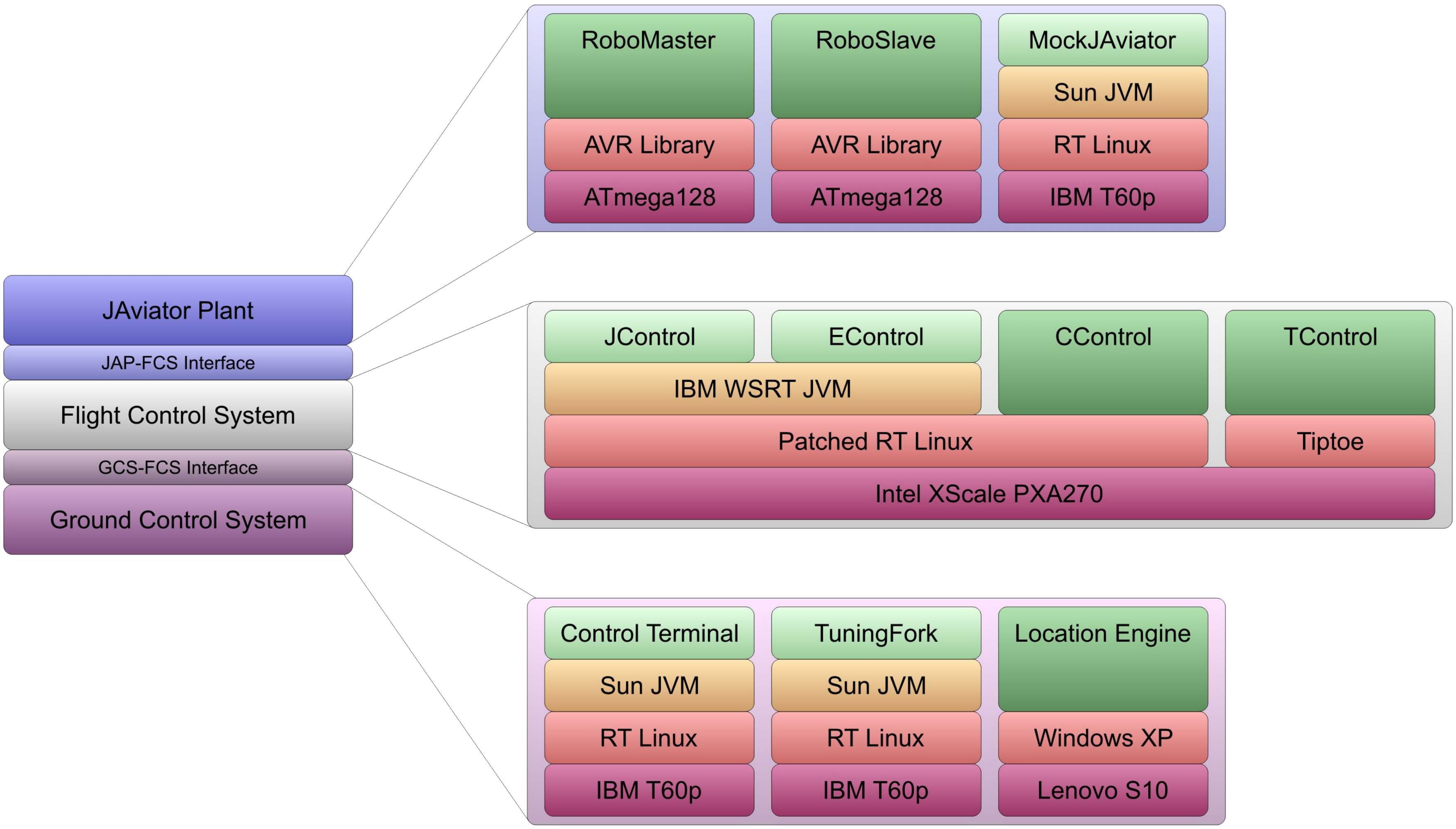
Control System Design – *Position Hold*

How to achieve a high degree of …

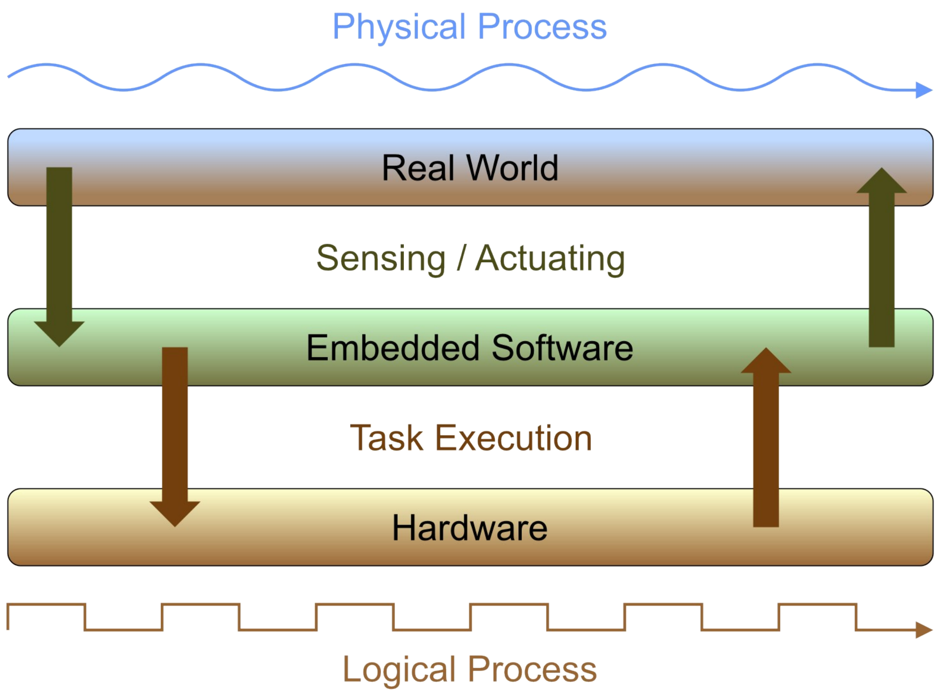
- Flexibility
- Maintainability
- Time Portability

?

Software Architecture – *System Layer Model*

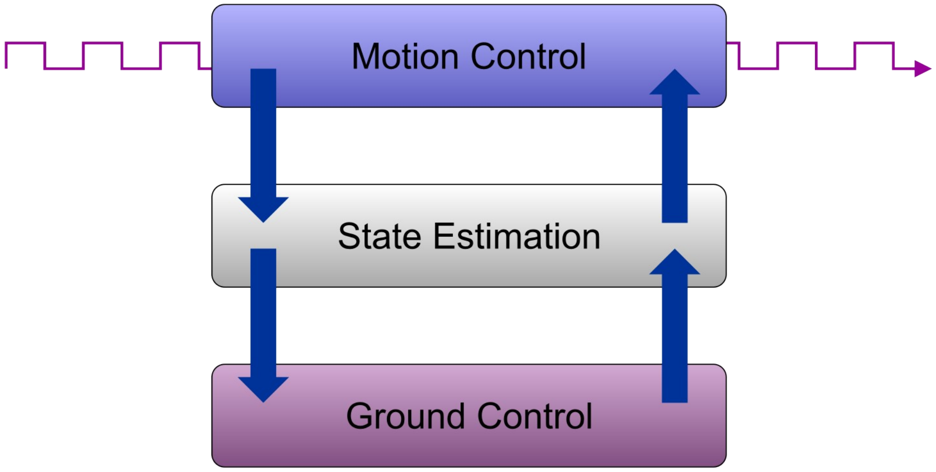


Software Architecture – *Logical-Timing Model*



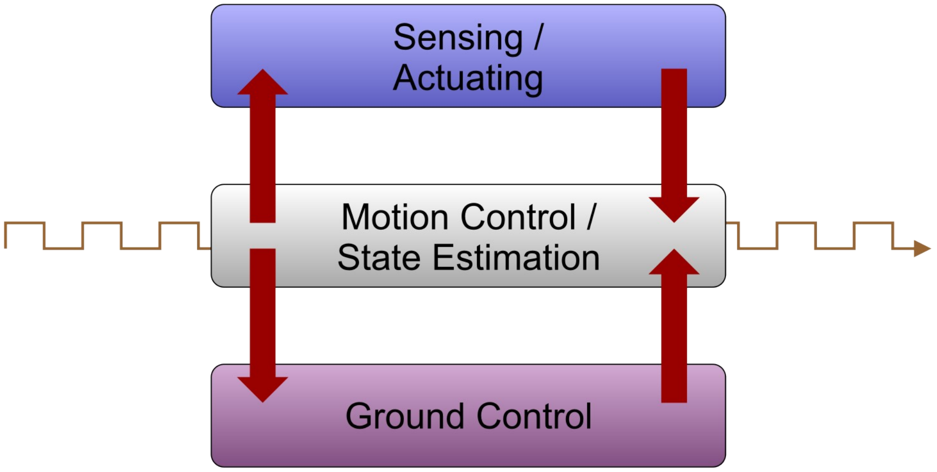
Software Architecture – *Timing Sources*

Hardware-Based Timing



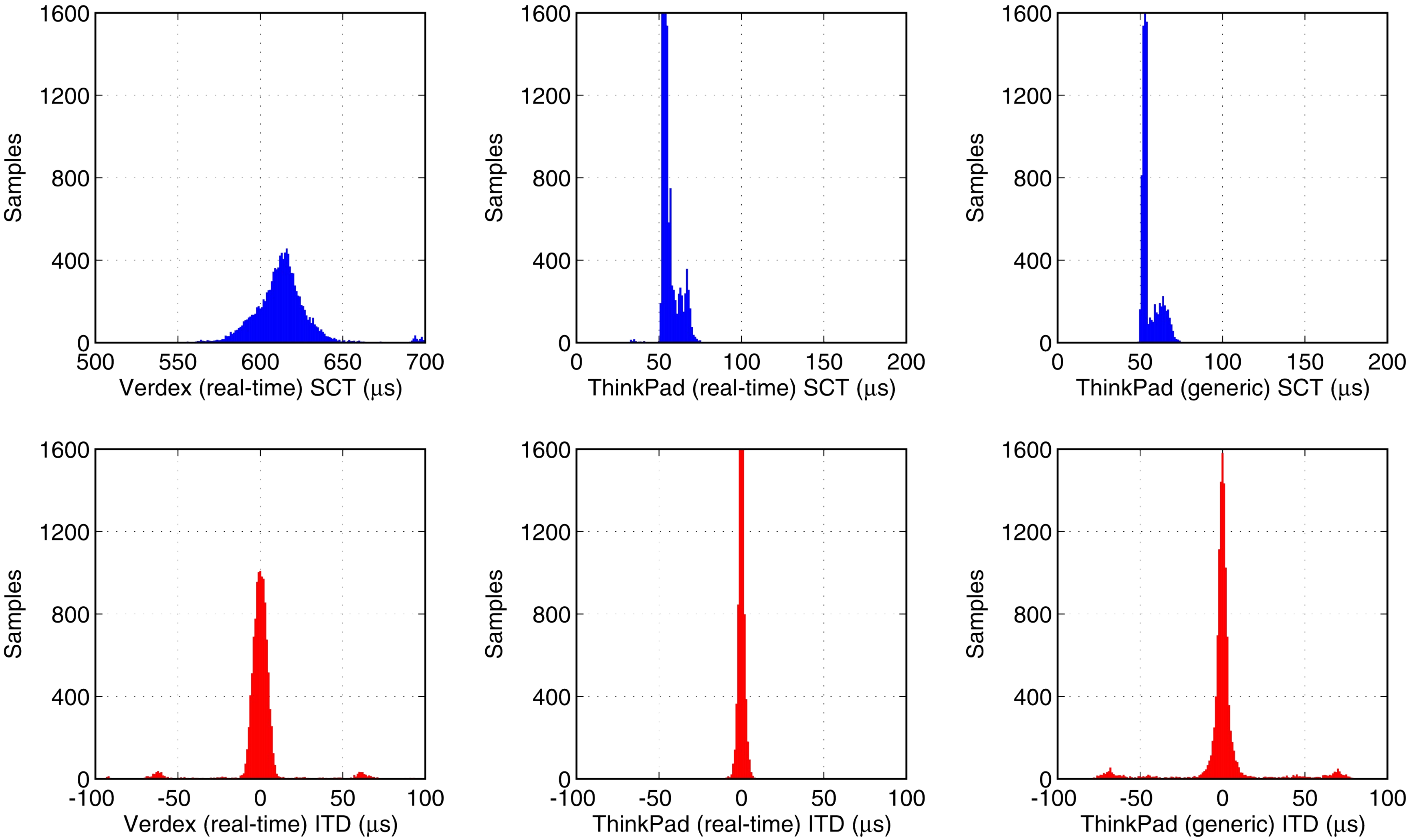
Event-Triggered Data Flow

Software-Based Timing



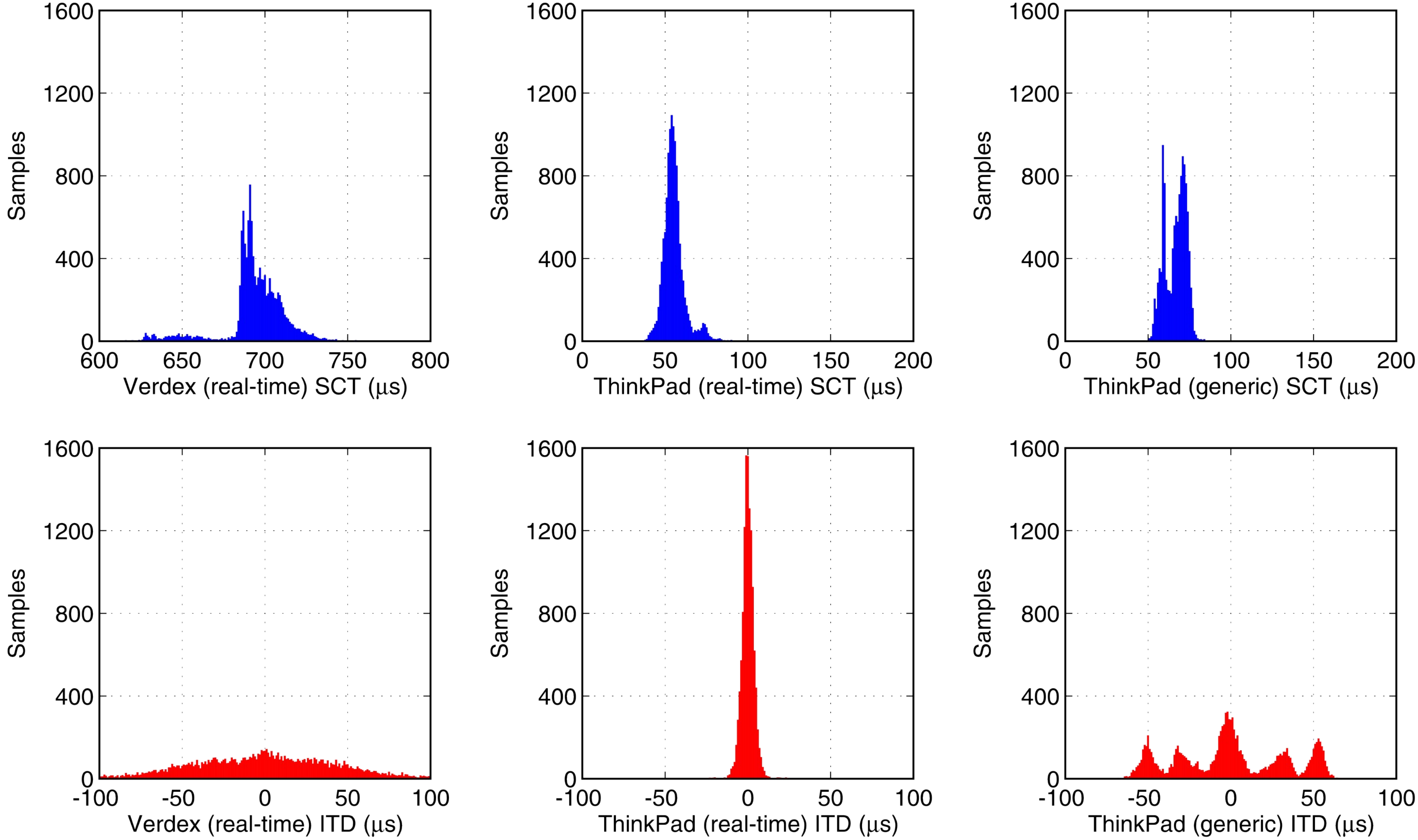
Time-Triggered Data Flow

Software Architecture – *Temporal Performance*



Signals Computation Times (top row) and Interarrival Time Deviations (bottom row) of the FCS with respect to ***low*** I/O load: standard communication between JAP, FCS, and GCS

Software Architecture – *Temporal Performance*



Signals Computation Times (top row) and Interarrival Time Deviations (bottom row) with respect to ***high*** I/O load: 130-MB file upload to the Verdex and playing a DVD on the ThinkPad

Conclusions

It was shown that …

- A symmetrical airframe design can provide much higher mechanical integrity than conventional airframe designs of similar weight and also enables the incorporation of ultra-thin materials.

- An electric propulsion system based on brushless-motor technology in conjunction with belt-drive gearing can achieve significantly higher efficiency than conventional electric propulsion systems.

- RFID-based position sensing is basically feasible for autonomous indoor navigation and allows to achieve reasonable position-hold accuracies similar to manually piloted flights.

- A control system can be designed to preserve its temporal behavior across different hardware platforms and in the presence of varying workload conditions without degradation in performance.

Thank You!

Questions?