Autonomous Quadrotor Control

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Computational
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The JAviator Project

- Collaborative research project of the
  - Computational Systems Group, Department of Computer Sciences, University of Salzburg
  - IBM T. J. Watson Research Center, Hawthorne, New York, USA

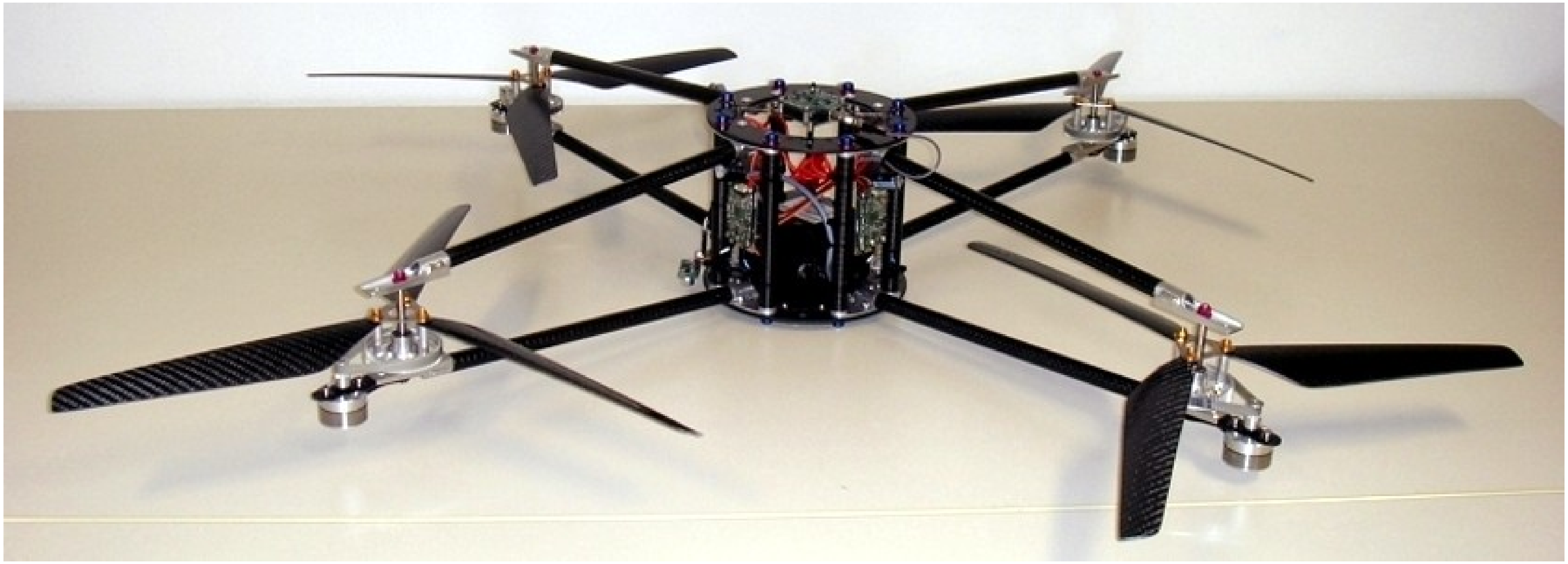
- Primary project goals are to
  - develop high-level real-time and concurrent programming abstractions for Java
  - provide an infrastructure that is time-portable
  - verify system on UAV (unmanned aerial vehicle)

Project Issues

- Design and build elaborate UAV platform
- Develop Java-based real-time control system
- Provide required Java real-time capabilities
- Provide time-portability among platforms
- Verify entire system to achieve project goals

The JAviator V1

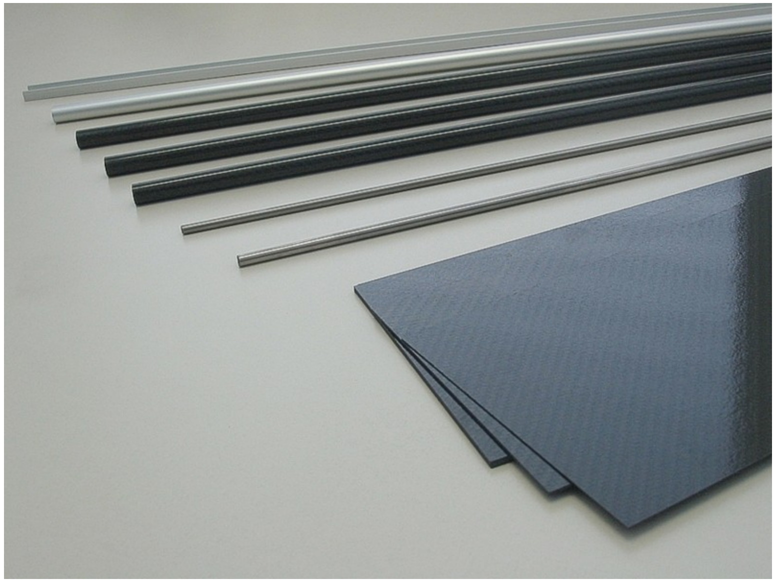
- Quadrotor model helicopter
  - built of high-quality materials like carbon fiber, aircraft aluminium, and medical titanium
  - equipped with custom-made 3-phase motors

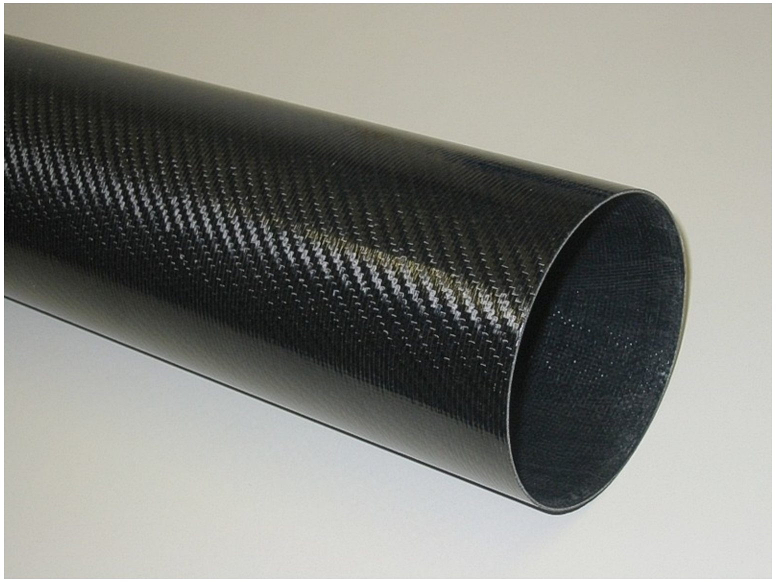


JAviator V1 Symmetry

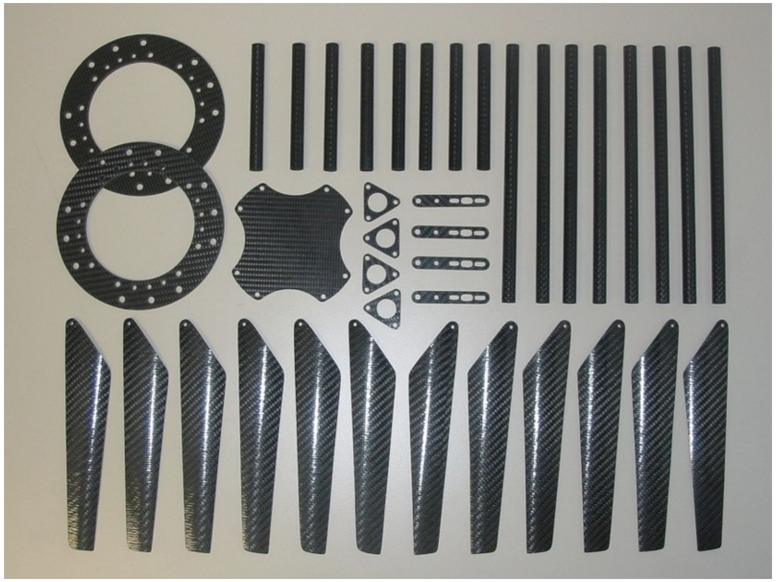
- Bicycle-wheel concept
  - as underlying frame design pattern
  - offers extremely high mechanical stability
  - enables the usage of very thin and light materials

Basic Components

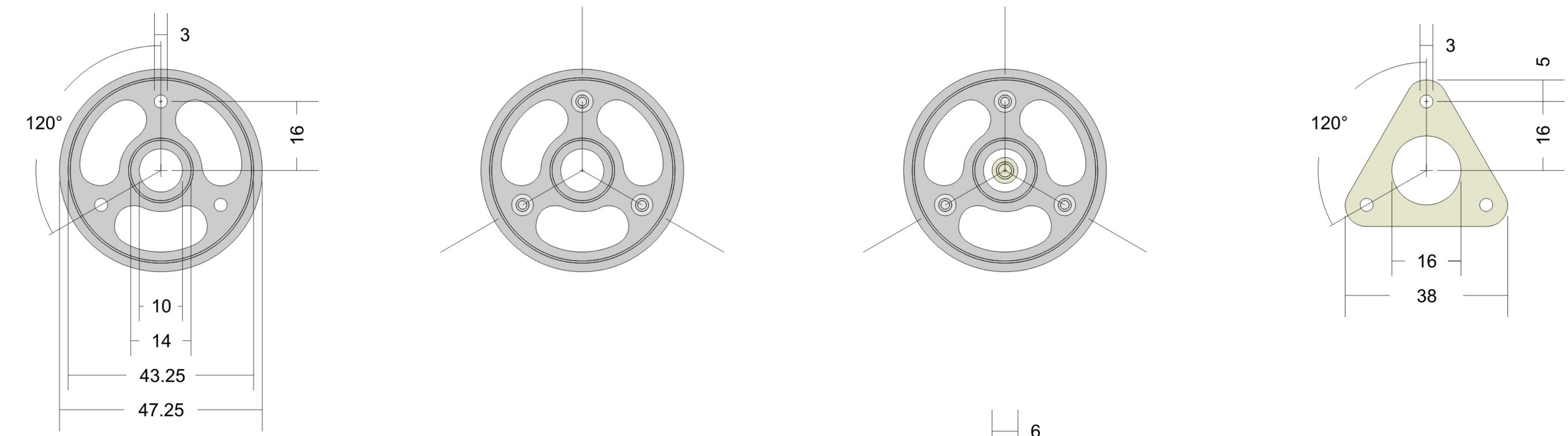


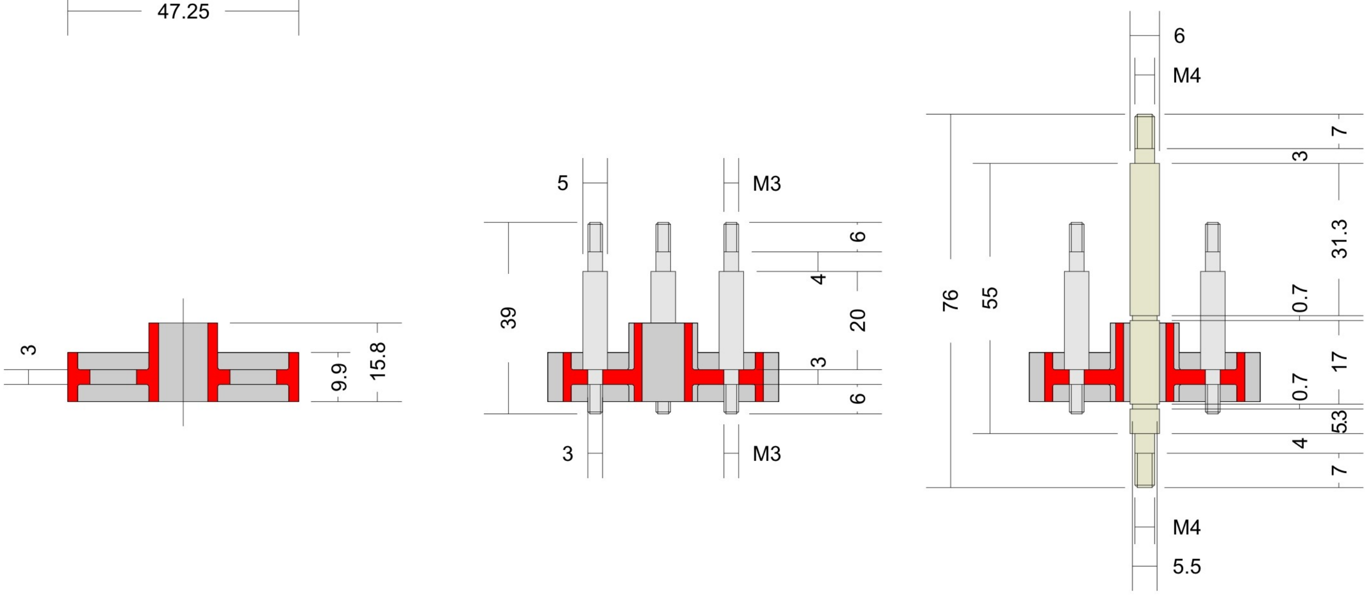


Machined Components



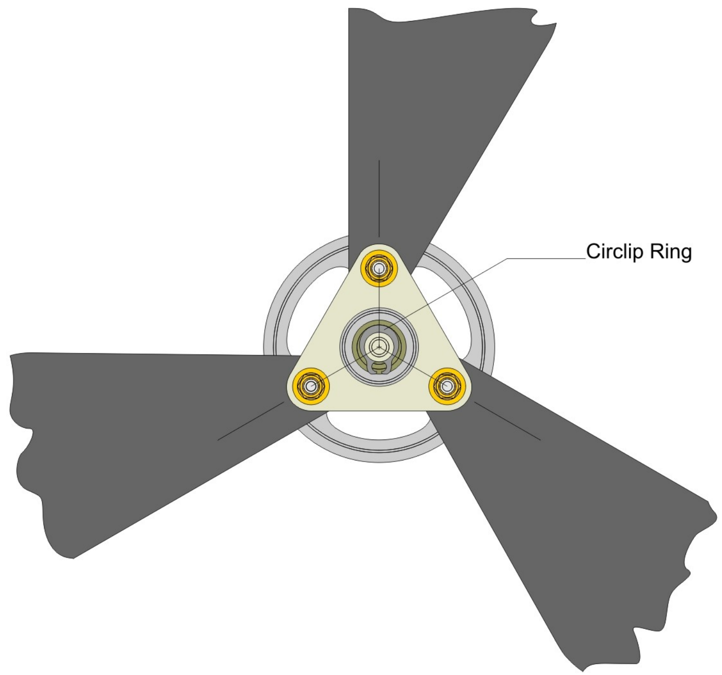
3-Blade Rotor Design

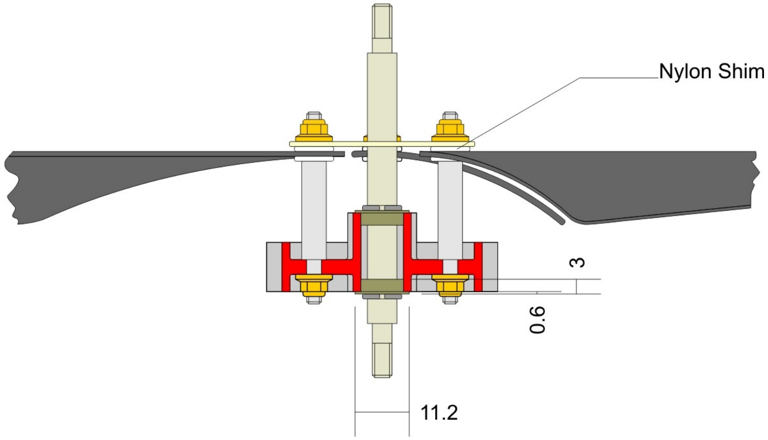


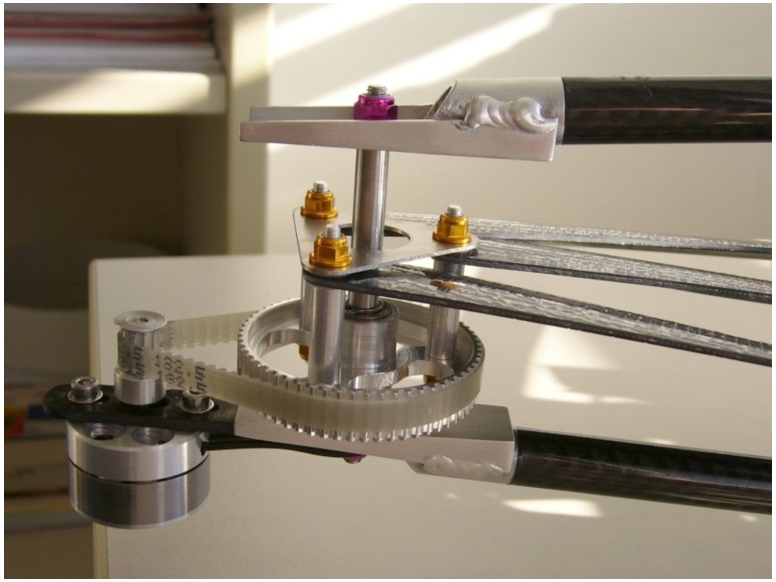


Gear: Aluminium Alloy
Shafts: Aluminium Alloy
Axle: Titanium Alloy
Triangle: Titanium Alloy

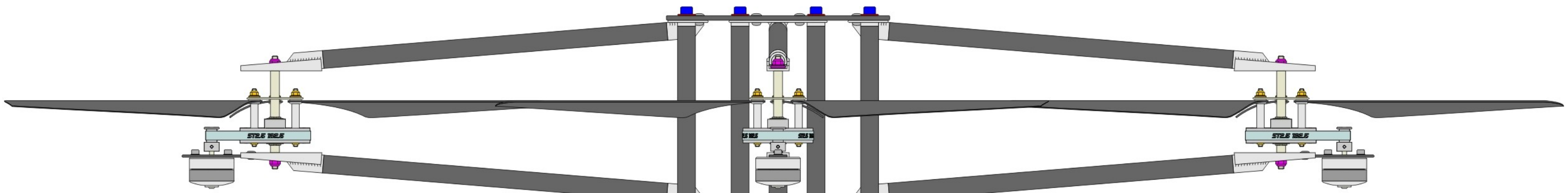
JAviator V1 / V2 Rotor

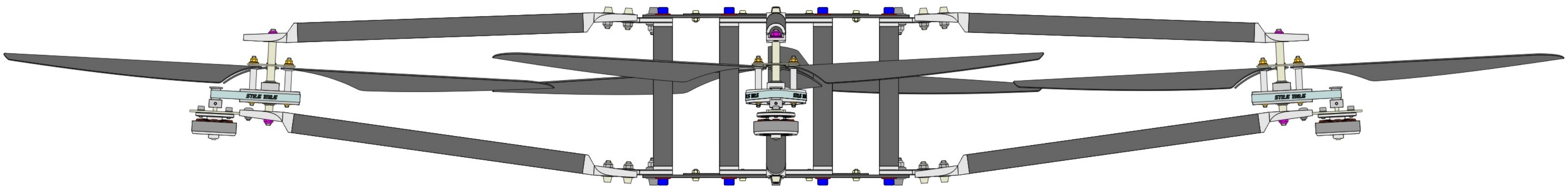




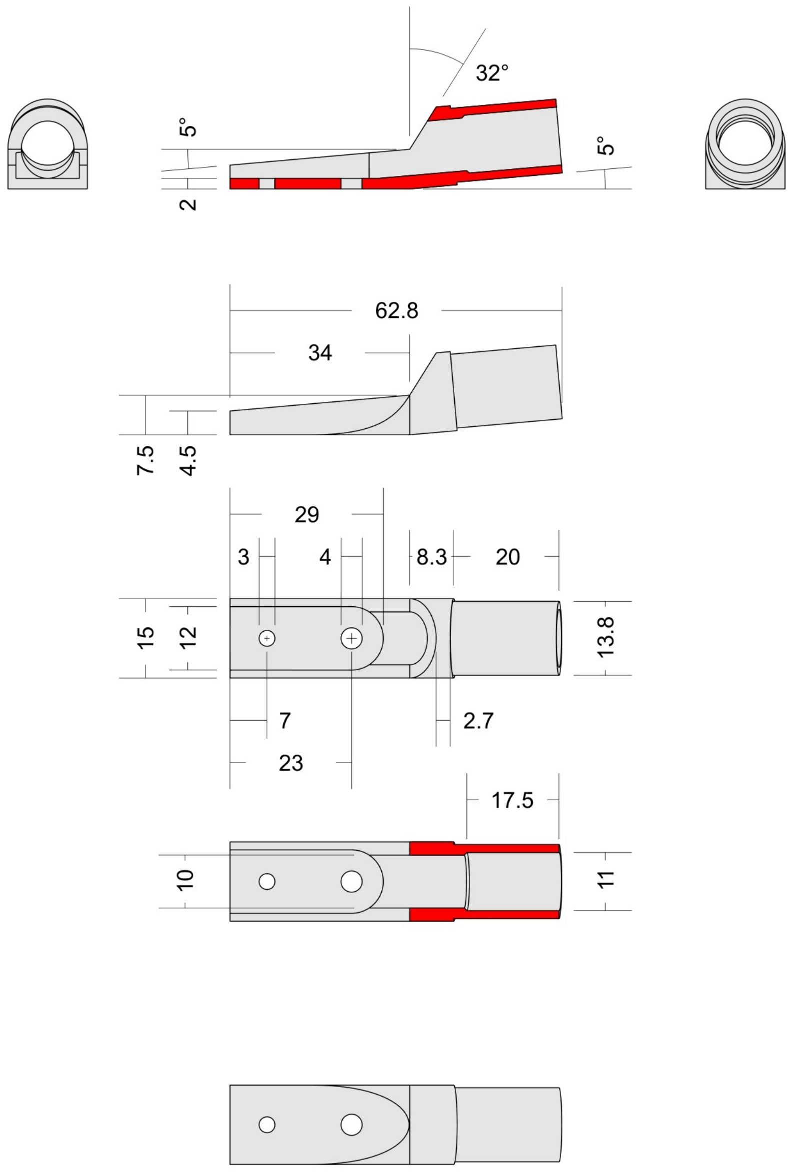


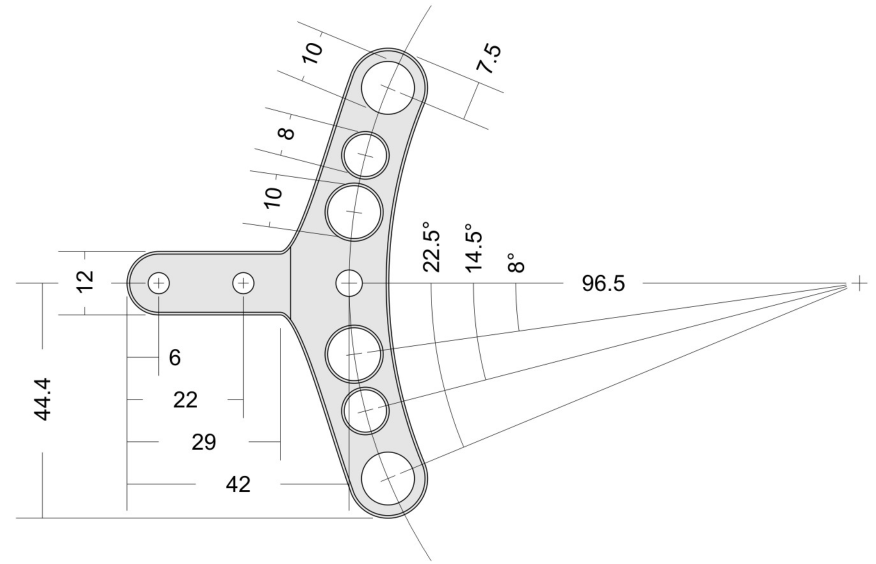
JAviator V1 vs. JAviator V2

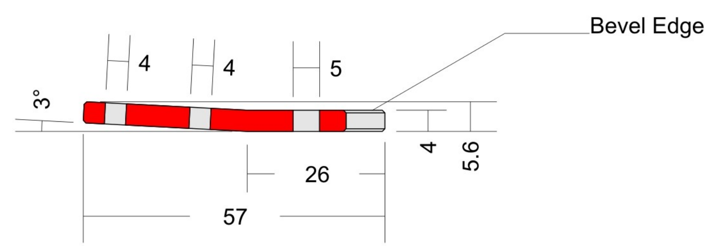




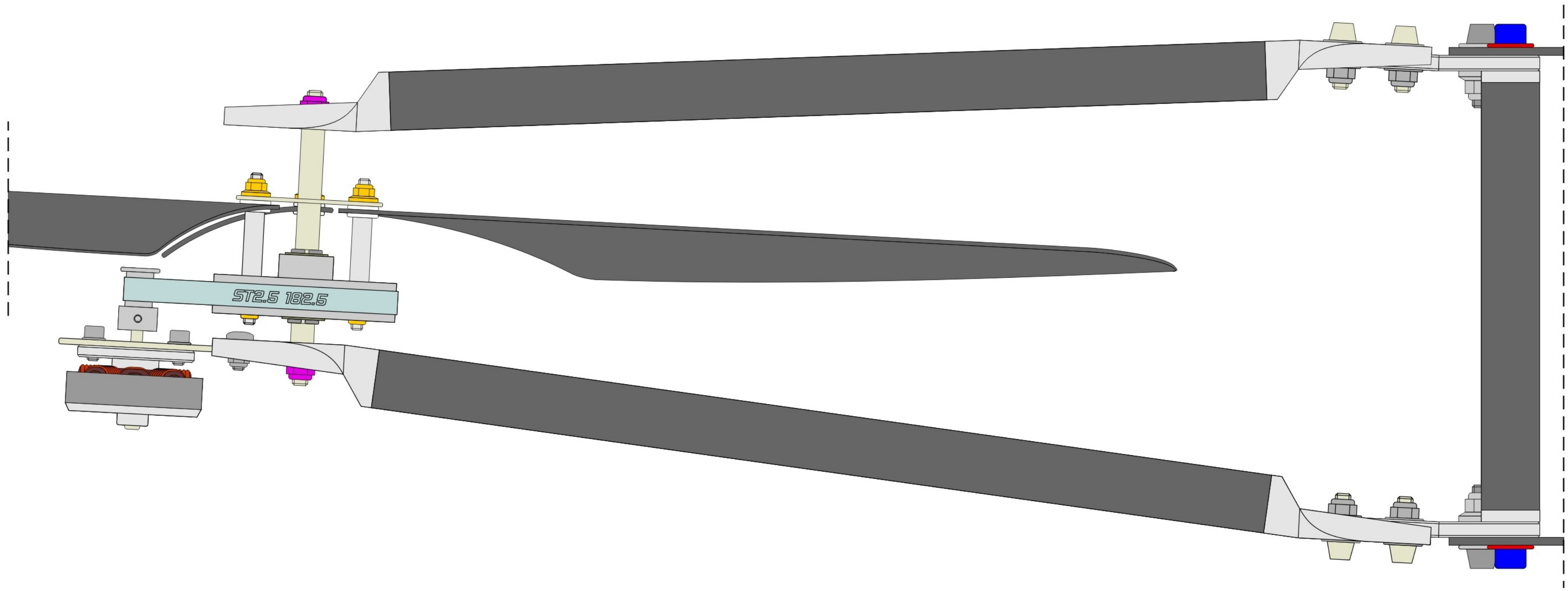
V2 Connecting Parts



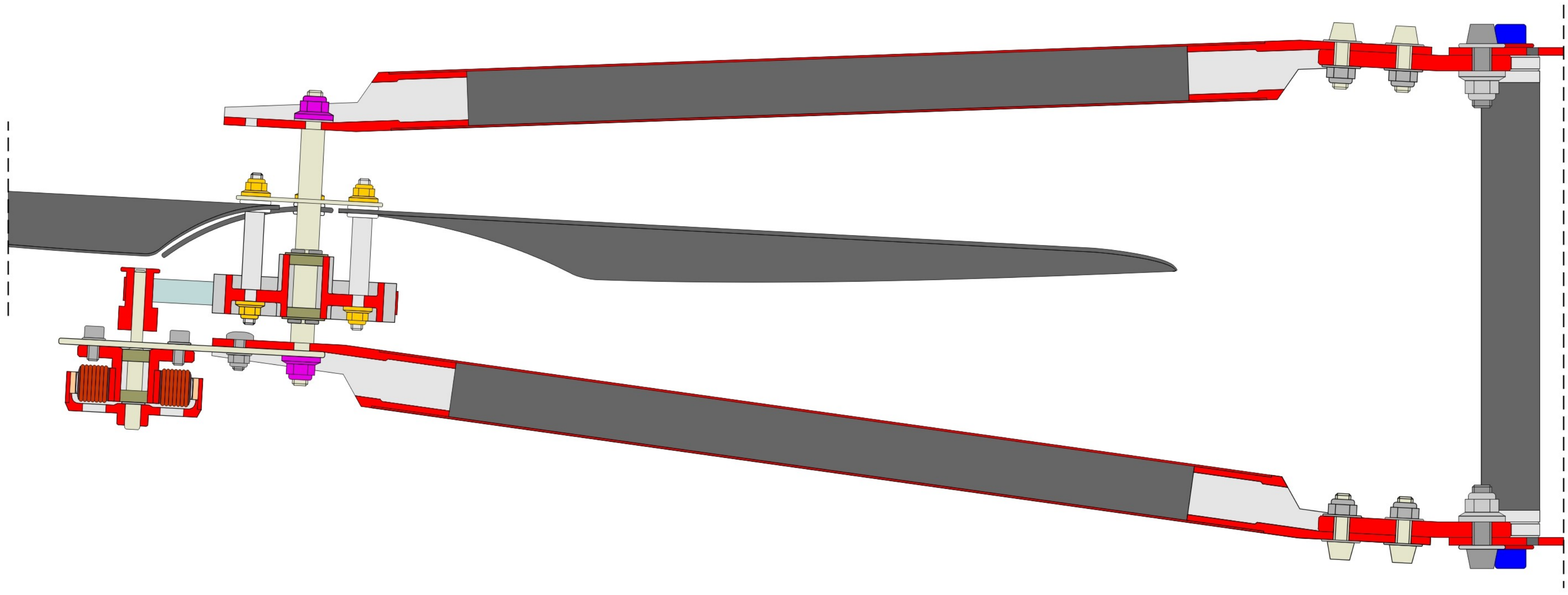




V2 Rotor-Arm Design

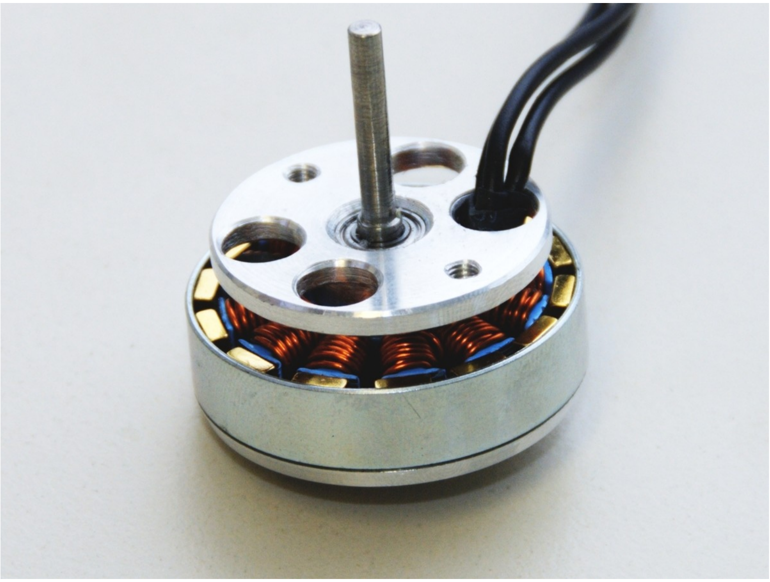


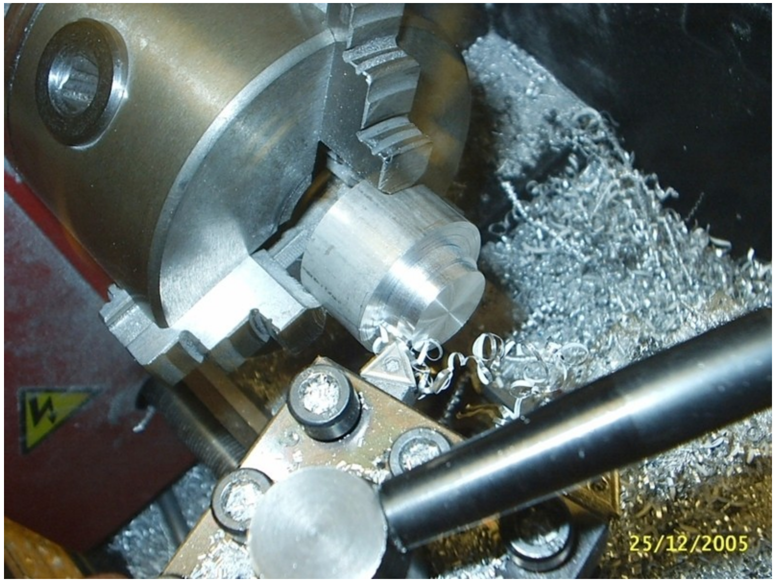
V2 Rotor-Arm Design



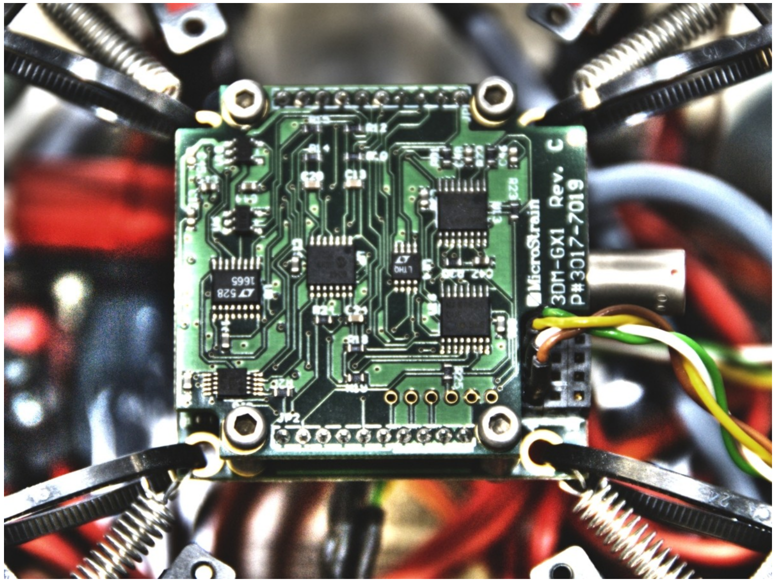
Electronic Components

- 3-phase motors:
  - 20mm height
  - 35mm diameter
  - 250W max power (17A at 15V DC)





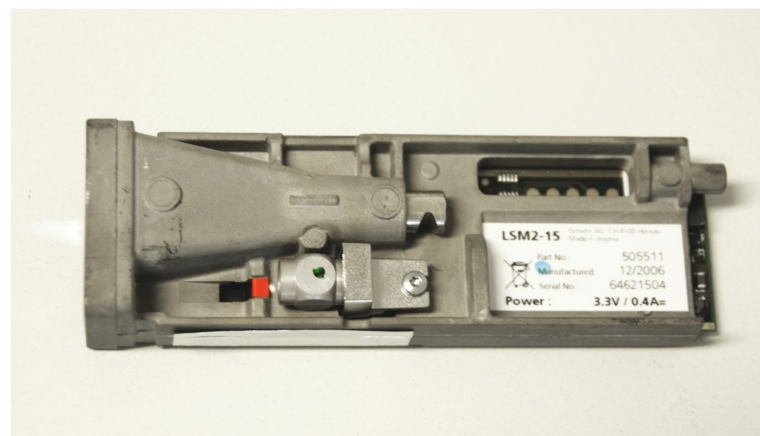
Electronic Components



MicroStrain 3DM-GX1 Gyro Sensor

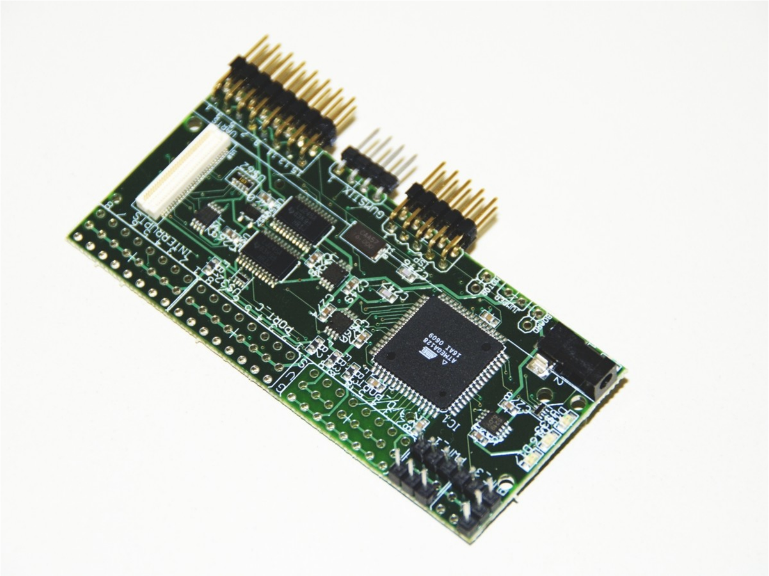
Dimetix LSM2-15 Laser Sensor (front)

Jeti SPIN 33 Motor Controller

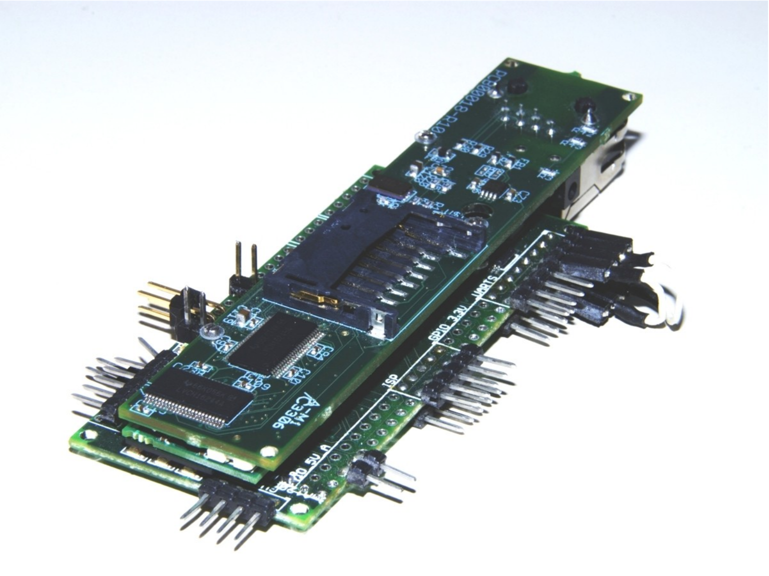


Dimetix LSM2-15 Laser Sensor (top)

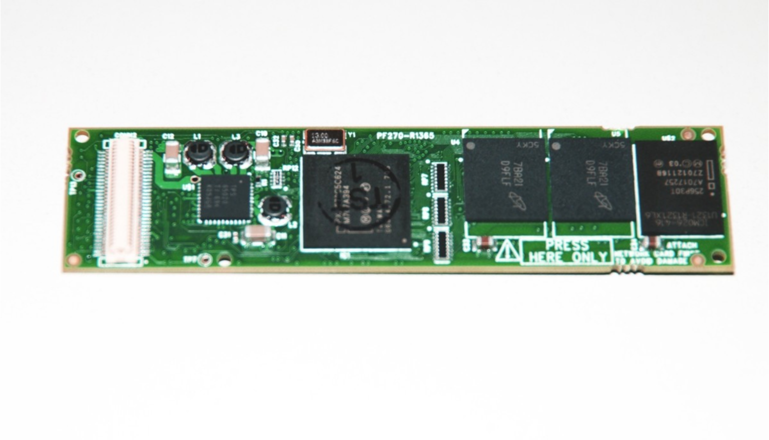
Electronic Components



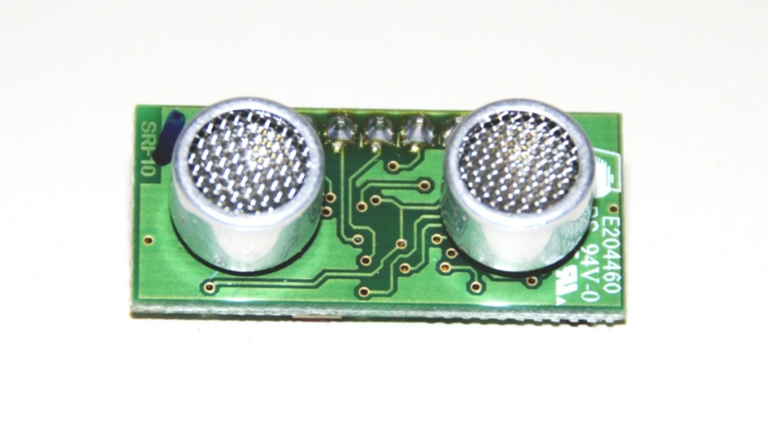
Robostix with Atmel Atmega 128 CPU



Robostix-Gumstix-NetMMC Sandwich



Gumstix with Intel XScale 400 CPU



Devantech SRF10 Ultrasonic Sensor

Manual Control vs. Autonomous Control

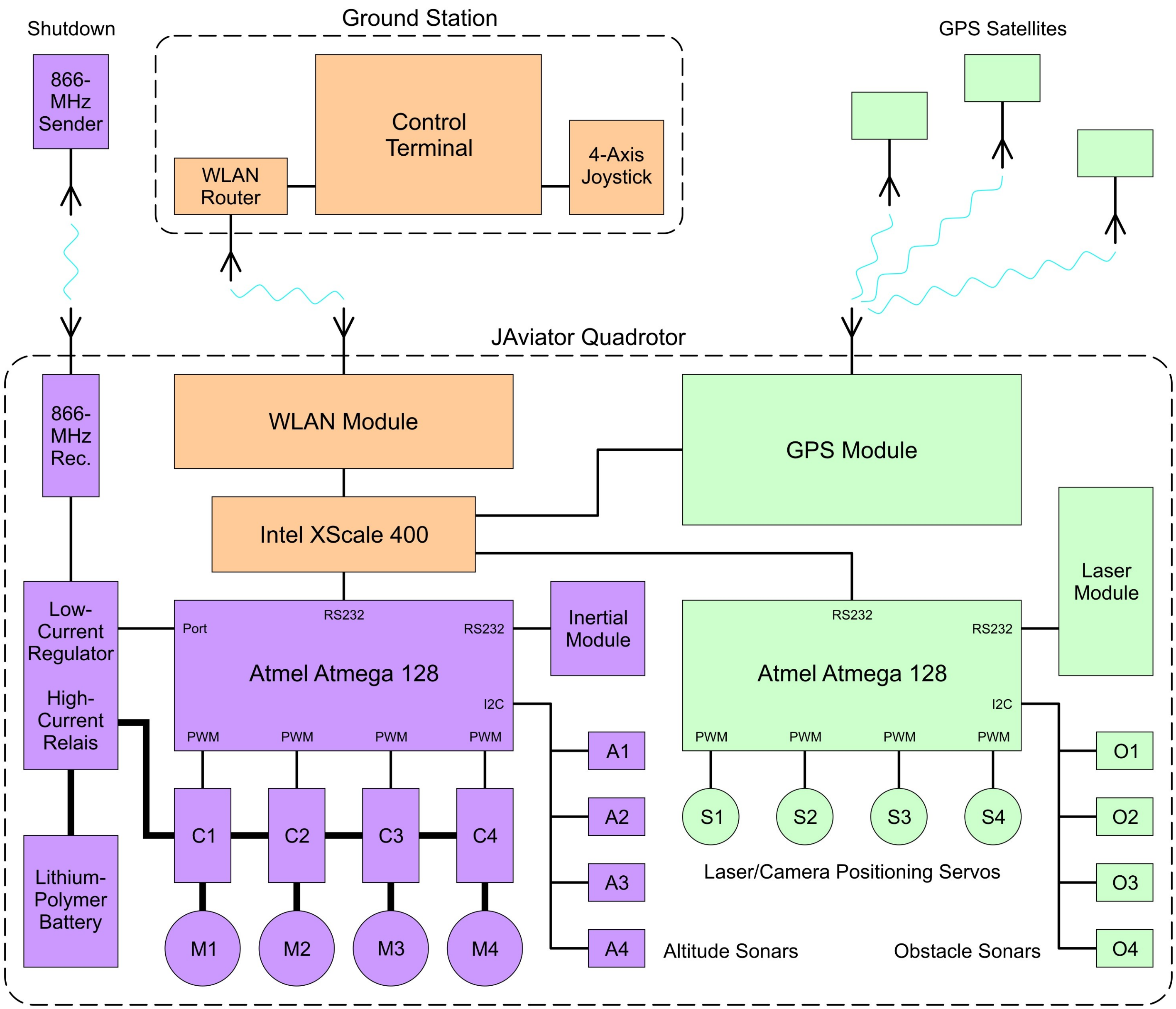
- Stabilization control needed only for roll, pitch, and yaw
- User recognizes significant attitude/altitude deviations (drift, wind, power leaks, …)
- User recognizes true position, ground surface, and obstacles
- User performs full navigation and trajectory control

- Stabilization control needed also for **altitude** (90% thrust)
- Sophisticated **sensing** needed to recognize significant attitude/altitude deviations
- Sufficient **position** (GPS) and obstacle sensing needed
- Stabilization-independent **trajectory** controller needed

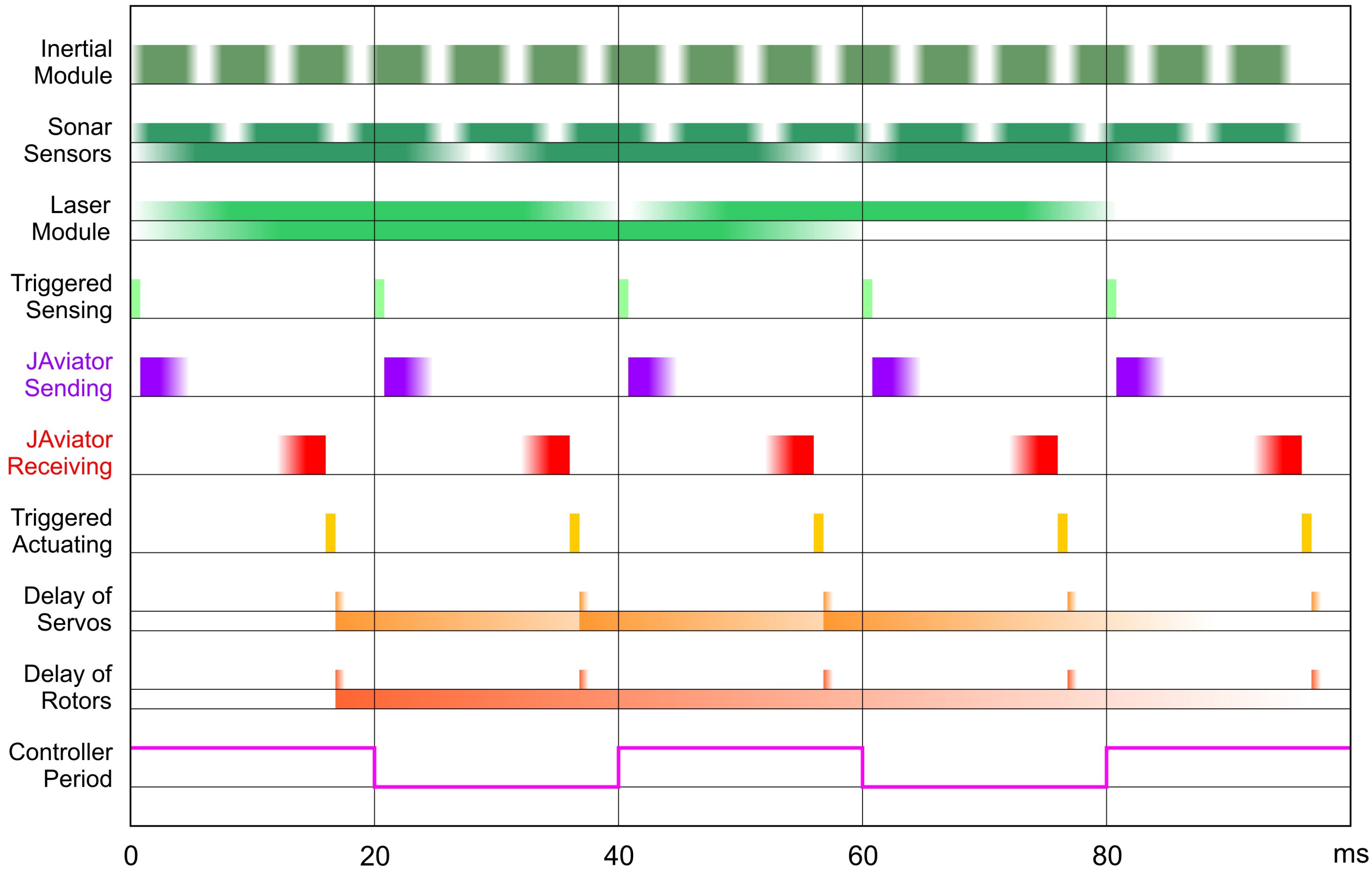
Control System Design

- Requirements:
  - 4 independent controllers to stabilize roll, pitch, yaw, and altitude
  - Controller period in the range of milliseconds
  - Hard real-time software
  - Reliable remote connection between JAviator and ground station
  - Sufficient computing power for autonomous flight
    - Onboard navigation
    - Trajectory control
    - Obstacle recognition

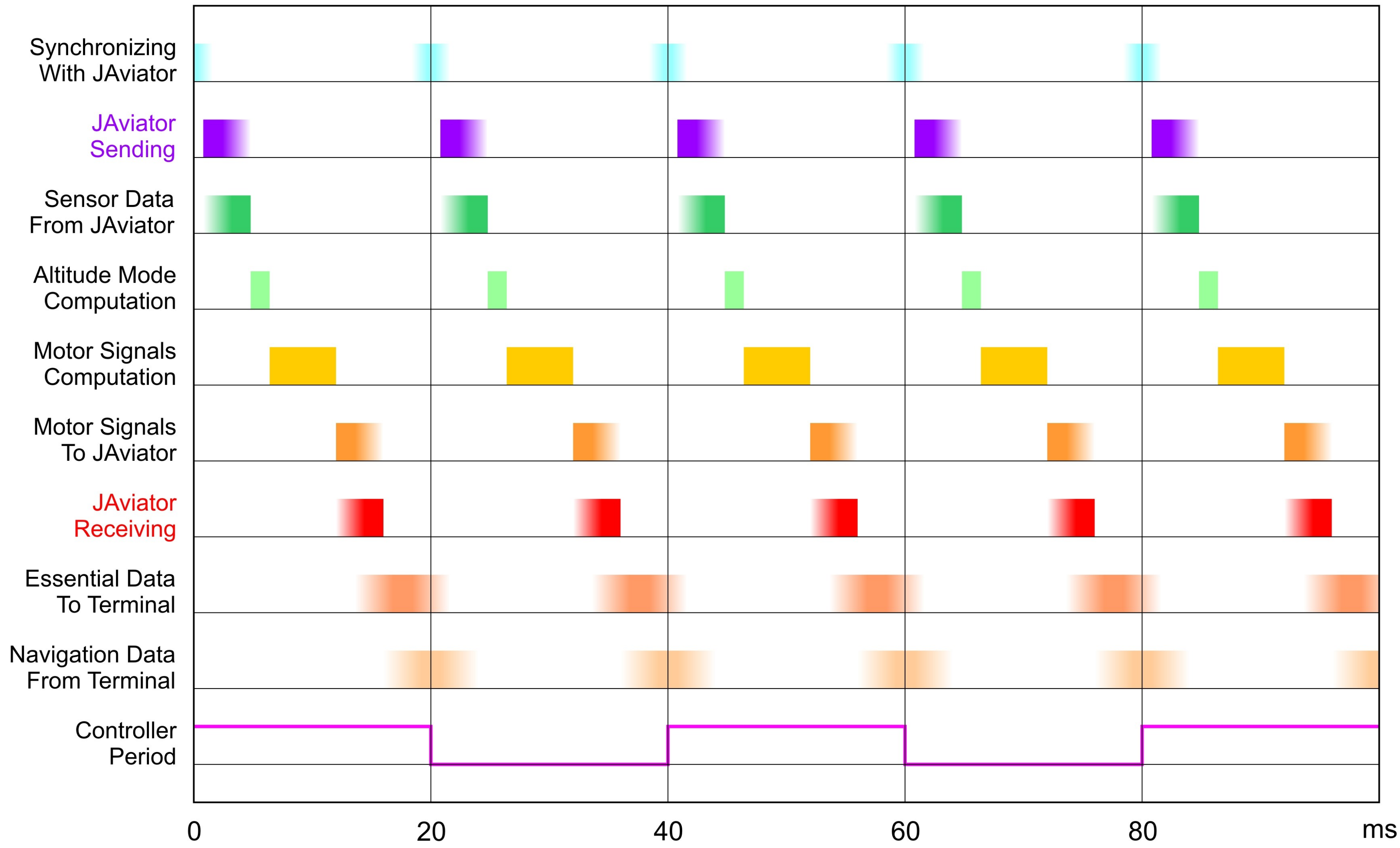
Embedded System



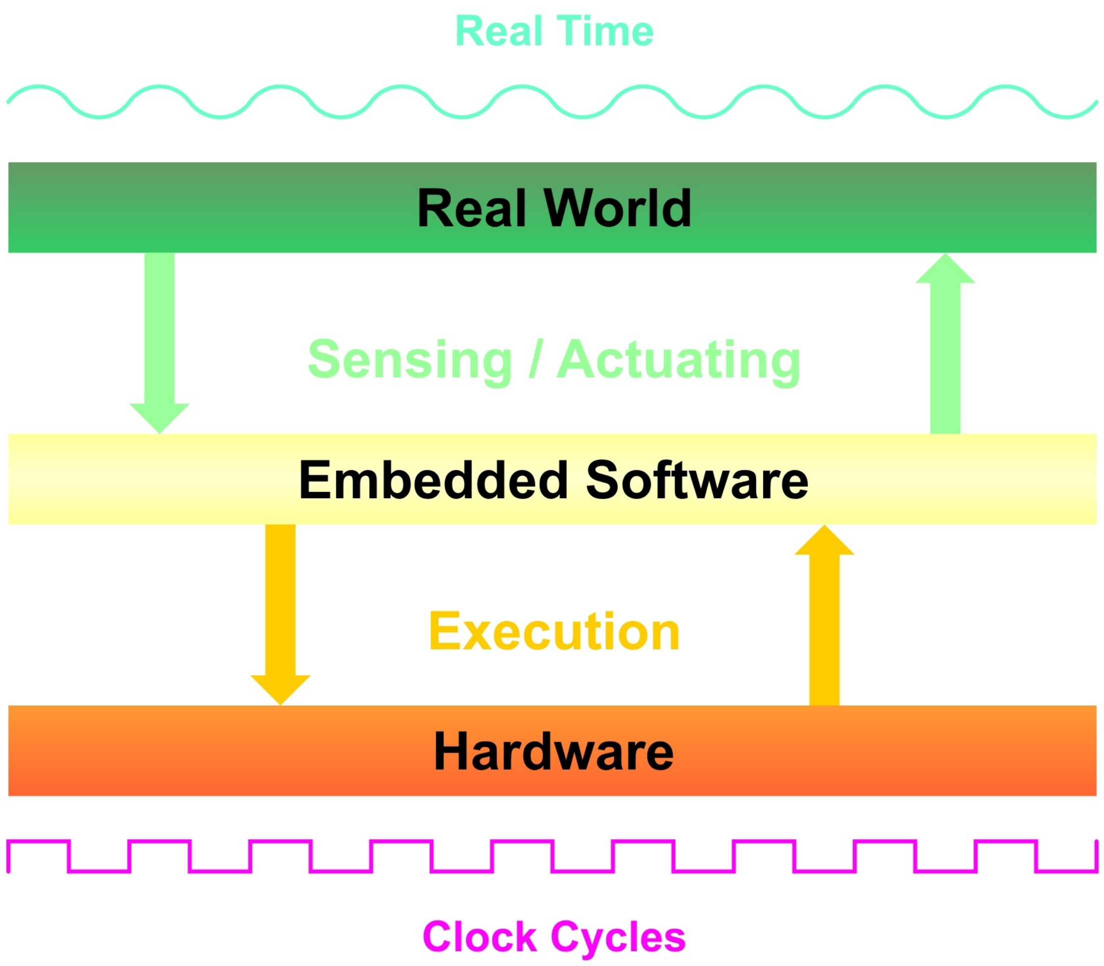
Robostix Timing



Gumstix Timing



Embedded Software



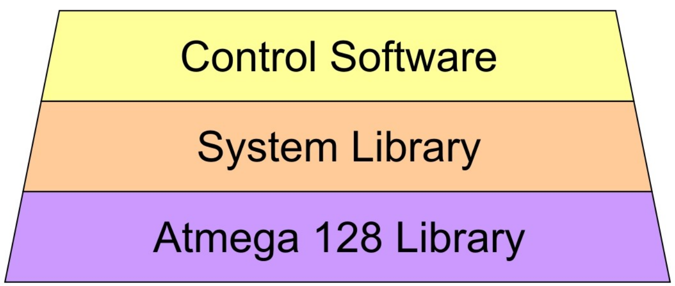
Control Software Design

- Atmega-based C software
  - Time-triggered sensing and actuating
  - Fully deterministic controller behavior

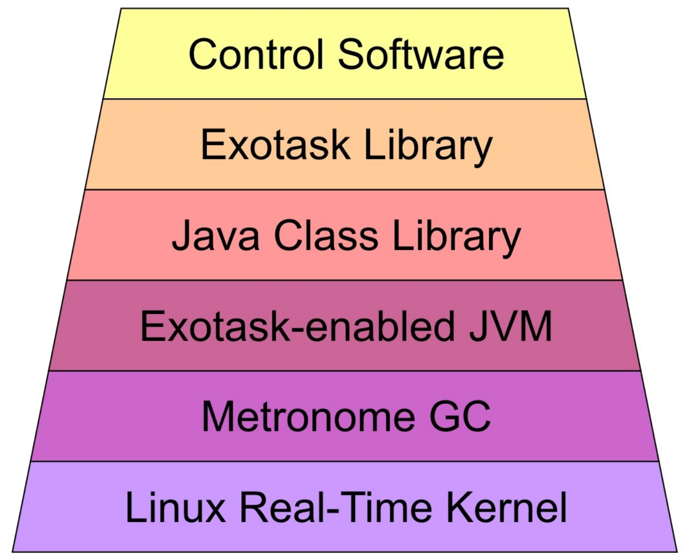
- Exotask-based Java software
  - Real-time software infrastructure
  - Each exotask has its own memory space
  - Each exotask has its own garbage collector
  - Exotask system provides time-portability
  - No change of original Java semantics

Software Hierarchy

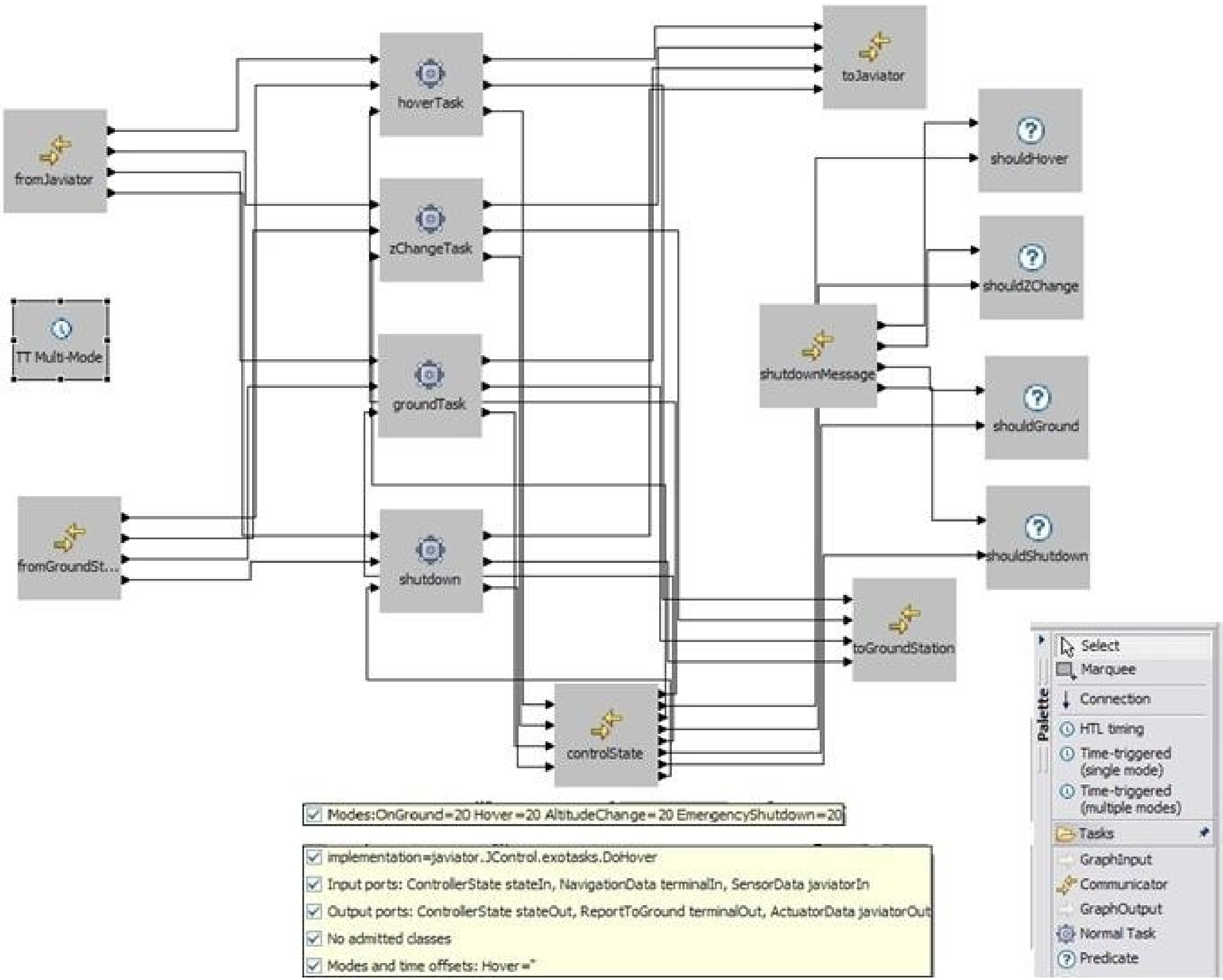
Atmel Atmega 128
(Robostix Extension Board)



Intel XScale 400
(Gumstix Connex Board)

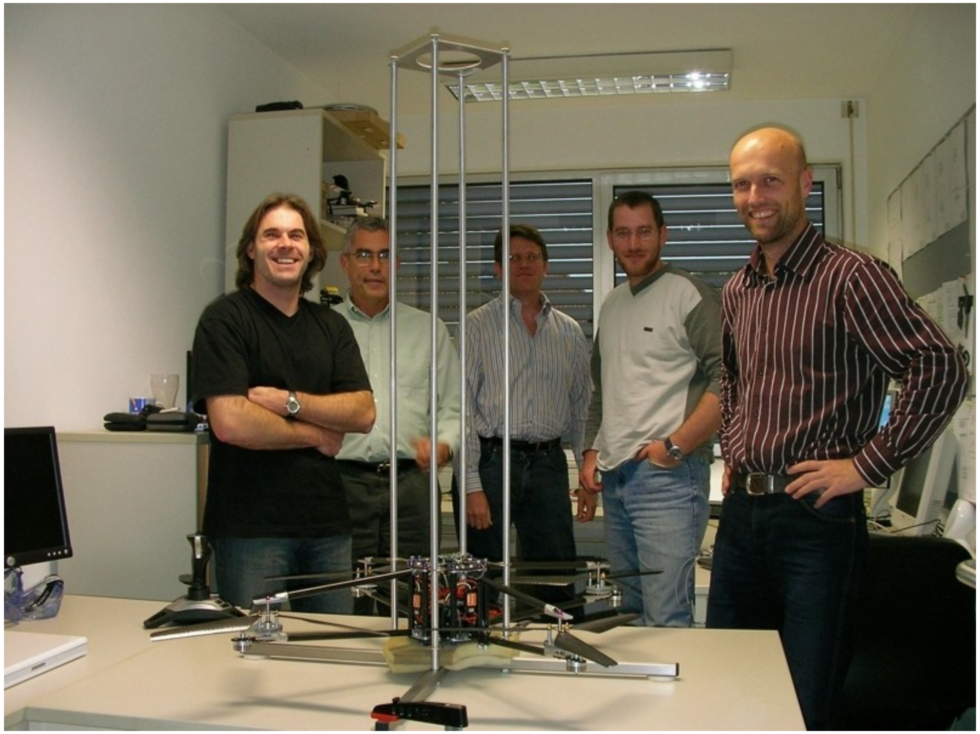


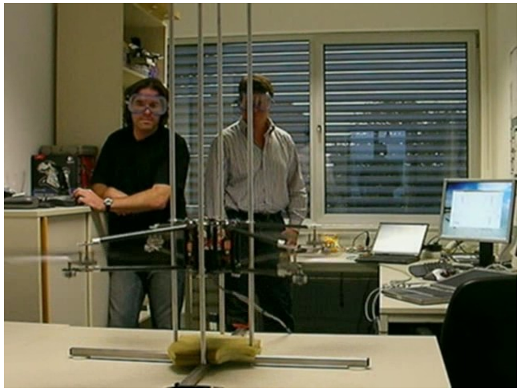
The Exotask Editor



First All-Java Flight

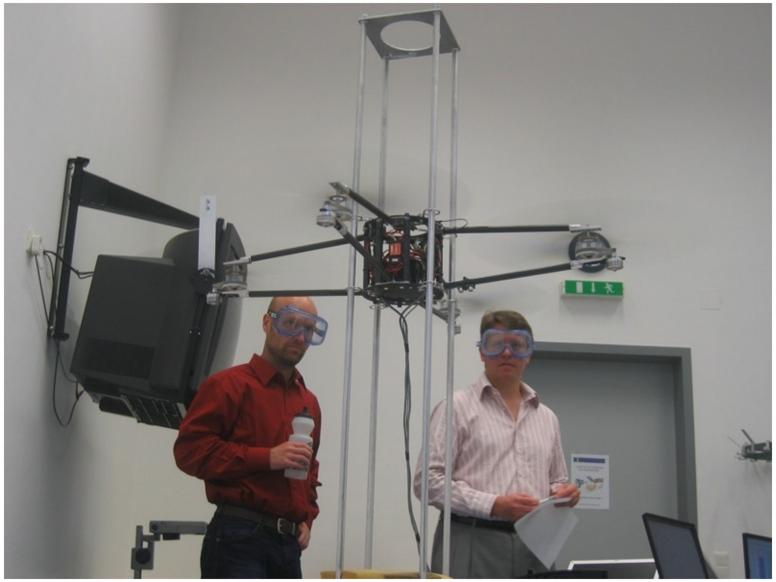
- Oct 4, 2006:
  - Spontaneous software test
  - System fully operational
  - First Java-based flight!

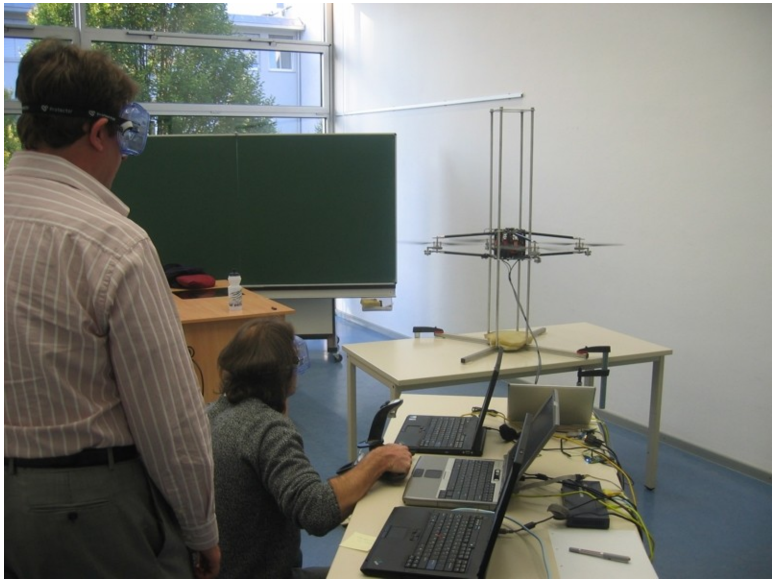




1st IBM Demo Session

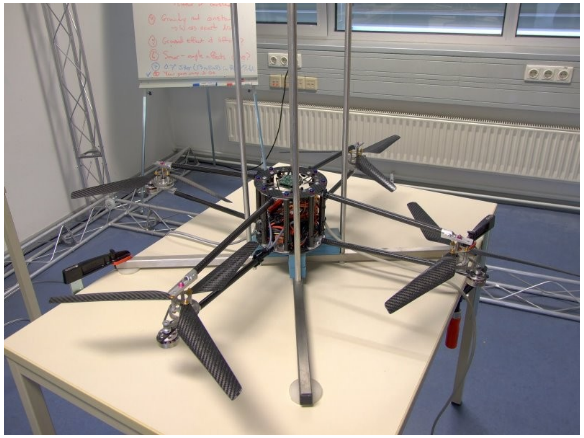
- Oct 5, 2006:
  - Official demo flights with IBM
  - Real-time tracing of entire system

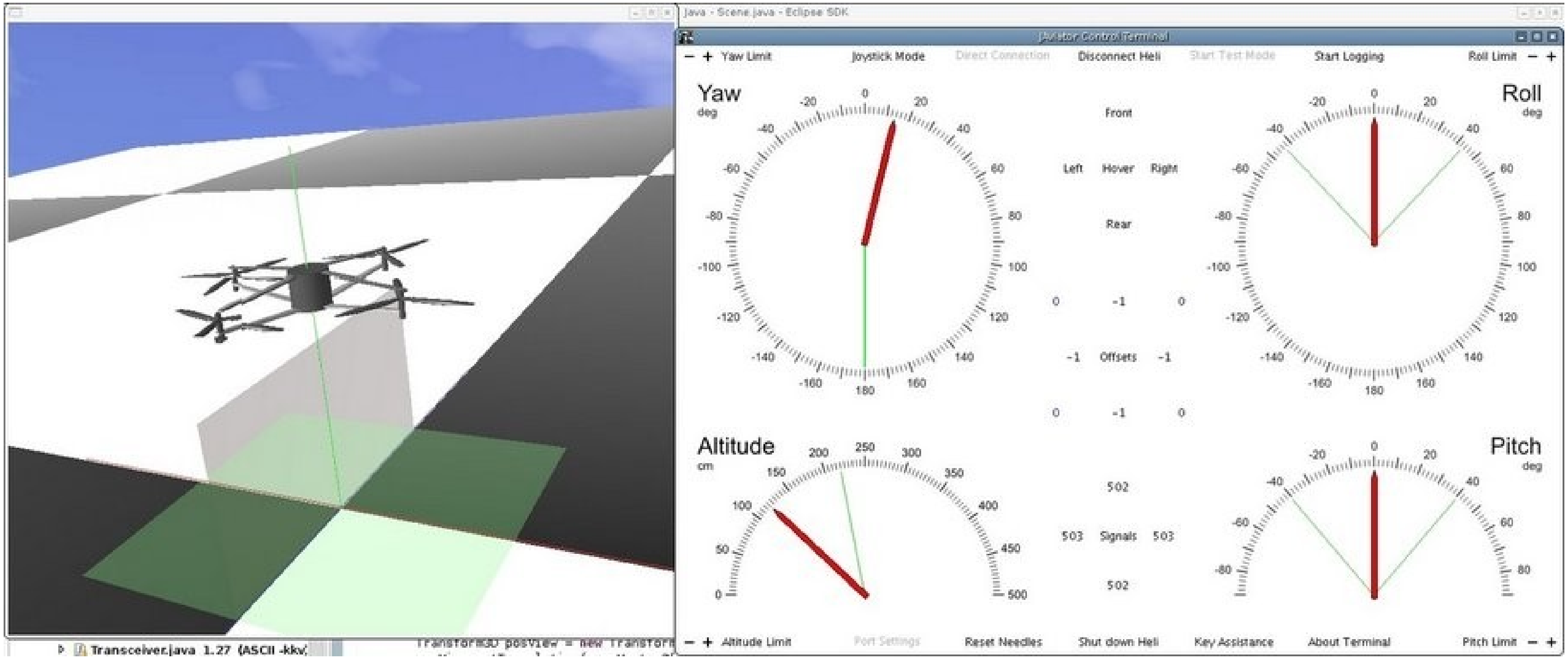




2nd IBM Demo Session

- May 24, 2007:
  - Demos with improved state-observer controller
  - 3-D environment added





Work In Progress

- Hardware: JAviator version 2
  - Laser for altitude and additional electronics
  - CNC-machined rotor and connecting parts
  - Custom-built high-precision rotor blades

- Software: Trajectory controller
  - Carrier-phase-GPS-based position recognition
  - Ultrasonic-based acquisition of obstacle data
  - Fully autonomous navigation and control

Thank You!

- Project Home Page:

  javiator.cs.uni-salzburg.at

- Published Paper:

  J. Auerbach, D.F. Bacon, D.T. Iercan, C.M. Kirsch, V.T. Rajan, H. Röck, and R. Trummer. Java Takes Flight: Time-Portable Real-Time Programming with Exotasks. In *Proc. ACM SIGPLAN/SIGBED Conference on Languages, Compilers, and Tools for Embedded Systems (LCTES)*. ACM Press, 2007.