MINESWEEPERS

TOWARDS A LANDMINE-FREE WORLD

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Unmanned Aerial Vehicles

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Unmanned Aerial Vehicles

- Introduction
- Modeling
- Control
- System Architecture
- Practical Considerations
- Resources

Introduction (1/2)

UAV Types

- Helicopter
- Fixed wing
- Hybrid

Distinctive Mission Qualities

- Flight speed
- Coverage
- Endurance
- VTOL/Hover
- Payload

UAV Applications

- Landmine detection
- Search and rescue
- Border patrol
- Surveillance
- Agriculture

Introduction (2/2)

Multi-rotor Helicopter

- Mechanically simple
- Favorable handling
- Symmetrical design

X650

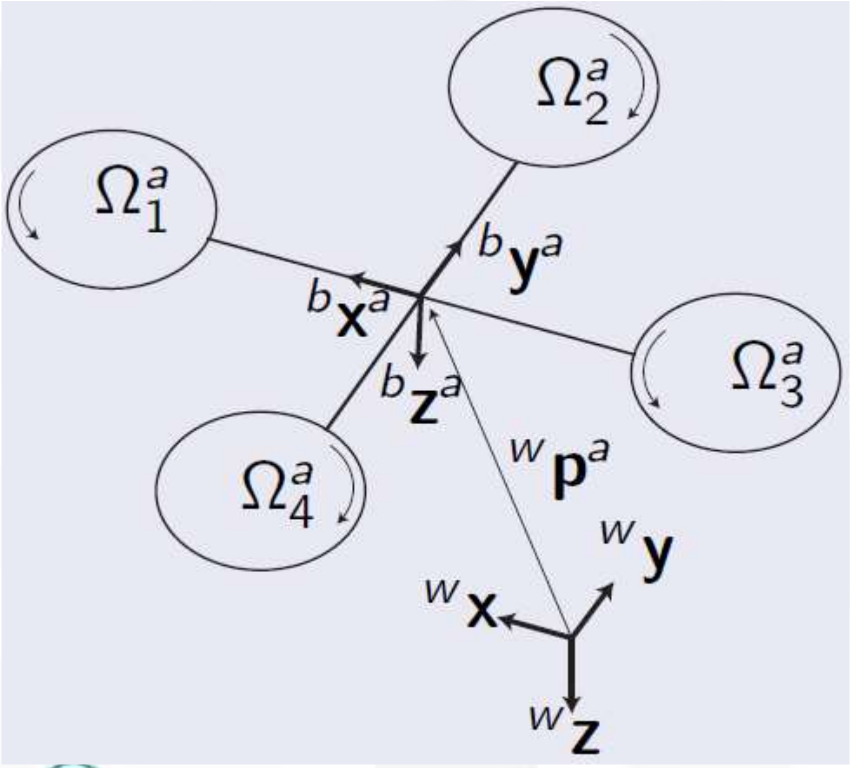
Conventional Helicopter

- Mechanical complexity (swash plate)

G2 Raptor

Quadrotor Modeling (1/3)

Quadrotor Architecture



Forces & Moments

F\M	Ω_1^a	Ω_2^a	Ω_3^a	Ω_4^a
Roll(M)		-		+
Pitch(M)	+		-	
Yaw(M)	+	-	+	-
Thrust(F)	+	+	+	+

$$F_i = k_F\,(\Omega_i^a)^2$$

$$M_i = k_M\,(\Omega_i^a)^2$$

Quadrotor Modeling (2/3)

- Rotational dynamics are computed using Euler equation

$$I\dot{\omega} + \omega \times I\omega = M$$

- Translational dynamics are computed using Newton equation

$$m\ddot{p} = RF + [0 \quad 0 \quad mg]$$

- Rotational matrix (R) is function in attitude and heading
- First order motor model

$$\frac{\Omega(s)}{V(s)} = K\frac{1}{\tau s + 1}$$

Quadrotor Modeling (3/3)

- System identification:
  - Motor/propeller model can identified experimentally
  - Aerodynamic coefficients can be identified experimentally
  - Some parameters can be directly measured
  - Inertia matrix can be approximated using simple shapes
- Control Challenges:
  - Nonlinear dynamics
  - Coupling
  - Under-actuation
- Remarks:
  - Dynamics can be linearized about operating point (hover)

Quadrotor Control (1/8)

Auto-pilot Levels	Pilot/GCS Commands	Features/ Challenges
Manual	Roll / Pitch / Yaw moments Thrust	No controller tuning Minimal sensory suite Almost impossible to pilot
Angular Velocity Stabilization	Roll / Pitch / Yaw velocity Thrust	Minimal controller tuning Gyroscopes needed Hard to pilot
Attitude & Heading Stabilization	Attitude (Roll & Pitch) Heading (Yaw) Thrust	Controller tuning IMU needed Good piloting skills to control position

Quadrotor Control (2/8)

Auto-pilot Levels	Pilot/GCS Commands	Features/ Challenges
Velocity Stabilization	Heading Linear velocities	Controller tuning GPS needed Basic piloting skills to control position
Waypoint Following	Position Altitude Heading	Controller tuning GPS + Barometer needed Basic piloting skills for takeoff and landing
Automatic Takeoff	Heading Position Altitude Takeoff command	Switching control GPS + Barometer + sonar needed Basic piloting skills for landing

Quadrotor Control (3/8)

Auto-pilot Levels	Pilot/GCS Commands	Features/ Challenges
Automatic Landing	Heading Position Altitude Landing command	Challenging Switching control GPS + Barometer + sonar + camera needed No piloting skills

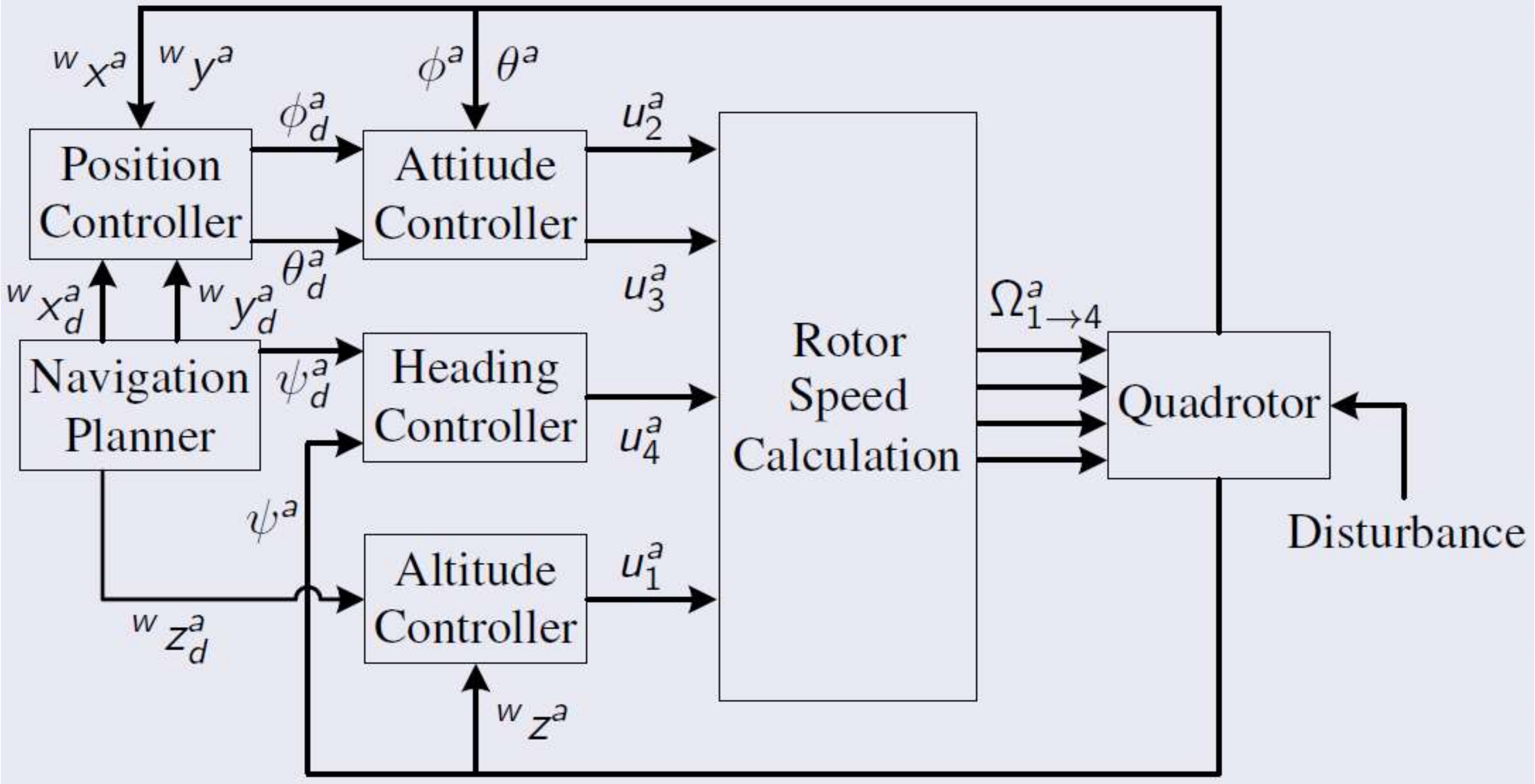
For higher level autonomy at least **waypoint following controller**:

- Path planning
- Mapping
- Return home, etc.

Quadrotor Control (4/8)

- Linear control
- Cascaded control architecture
- Control inputs are moments and delta thrust (converted to rotor speeds)
- Inner-loop controller outputs are desired roll, pitch and yaw angles
- Outer-loop controller outputs are desired position and altitude
- Remarks:
  - Mercator projection can be used to convert lat/lon/alt from GPS to x/y/z positions relative to a reference lat/lon/alt point
  - Inertial navigation systems (INS) should be implemented from improved positioning accuracy

Quadrotor Control (5/8)

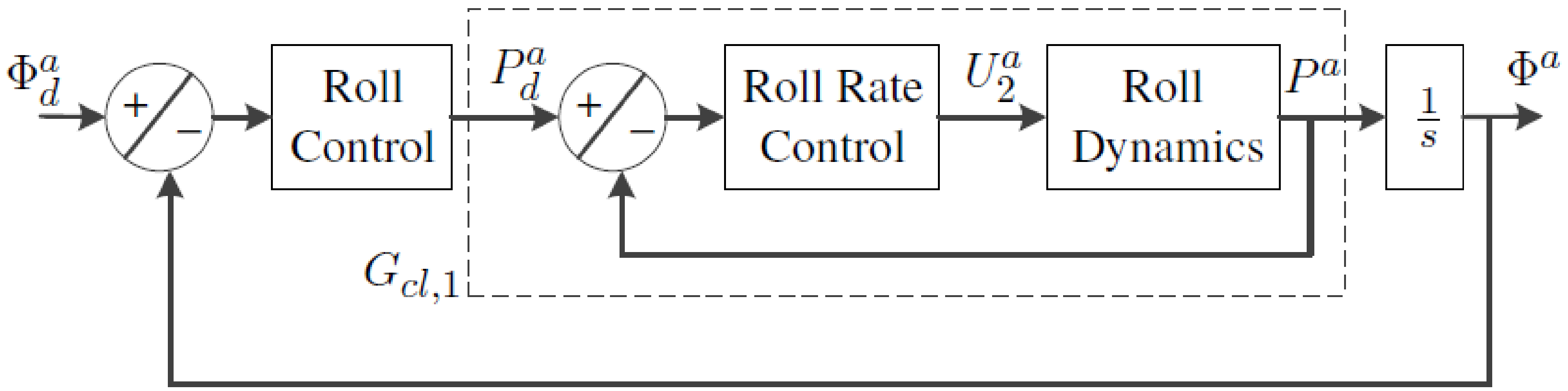


Quadrotor Control (6/8)

- **Differential** Rotor speeds are calculated from control inputs
- Hovering rotor speeds should be added to differential speeds

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix}^a = \begin{bmatrix} k_F & k_F & k_F & k_F \\ 0 & -k_F & 0 & k_F \\ k_F & 0 & -k_F & 0 \\ k_M & -k_M & k_M & -k_M \end{bmatrix} \begin{bmatrix} \Omega_1^2 \\ \Omega_2^2 \\ \Omega_3^2 \\ \Omega_4^2 \end{bmatrix}^a$$

Quadrotor Control (7/8)



$$p_d^a \triangleq k_{p,2}^a\left(\phi_d^a - \phi^a\right) + k_{i,2}^a \int_0^t \left(\phi_d^a - \phi^a\right) dt + k_{d,2}^a \frac{d\left(\phi_d^a - \phi^a\right)}{dt}$$

$$u_2^a = k_{p,1}^a\left(p_d^a - p^a\right) + k_{i,1}^a \int_0^t \left(p_d^a - p^a\right) dt$$

Quadrotor Control (8/8)

Remarks:

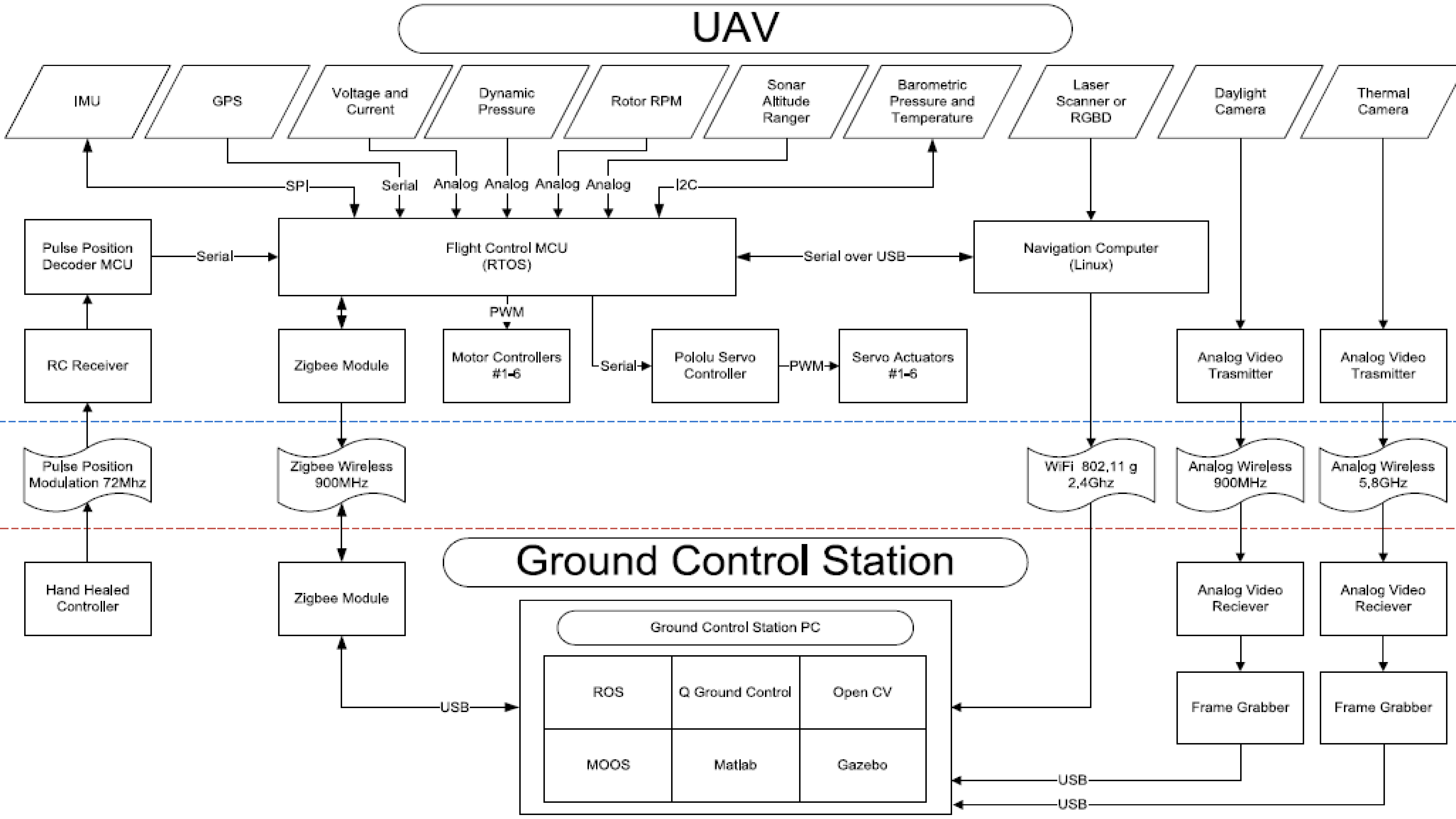
- Proper modeling and system identification reduces controller development time
- High inner-loop controller bandwidth
- Inner-loop controller is tuned first followed by the outer-loop controller
- Controller output saturation
- Piloting skills needed for controller tuning
- Actuator saturation and integrator wind-up
- Controller sensitivity to mass/inertia variations
- EKF for state estimation

System Architecture (1/3)

- Main system components:
  - UAV
  - Propulsion (Brushless DC motors, ESC, propeller)
  - Lithium polymer batteries
  - Onboard Sensors: IMU, GPS, barometer, etc.
  - Onboard micro-controller / single board computer
  - Communication modules
  - Ground control station
  - Safety pilot
  - Kill switch

System Architecture (2/3)

- Ground control station:
  - Monitoring:
    - Display telemetry data
    - Health
  - Visualization
    - Platform orientation
    - Position and heading on map
  - Functional
    - Waypoint transmission
    - Altitude and heading transmission
    - Mission specific


UAV
IMU
GPS
Voltage and Current
Dynamic Pressure
Rotor RPM
Sonar Altitude Ranger
Barometric Pressure and Temperature
Laser Scanner or RGBD
Daylight Camera
Thermal Camera
SPI
Serial
Analog
Analog
Analog
Analog
I2C
Pulse Position Decoder MCU
Serial
Flight Control MCU (RTOS)
Serial over USB
Navigation Computer (Linux)
PWM
RC Receiver
Zigbee Module
Motor Controllers #1-6
Serial
Pololu Servo Controller
PWM
Servo Actuators #1-6
Analog Video Trasmitter
Analog Video Trasmitter
Pulse Position Modulation 72Mhz
Zigbee Wireless 900MHz
WiFi 802,11 g 2,4Ghz
Analog Wireless 900MHz
Analog Wireless 5,8GHz
Ground Control Station
Hand Healed Controller
Zigbee Module
Ground Control Station PC
ROS
Q Ground Control
Open CV
MOOS
Matlab
Gazebo
USB
Analog Video Reciever
Analog Video Reciever
Frame Grabber
Frame Grabber
USB
USB

Practical Considerations

DIY

- Lightweight components
- Propulsion sizing for payload
- Battery sizing for endurance
- Sensor and payload mounting
- Noise/Vibration suppression
- Controller implementation
- GCS interfacing

Ready Kit

- Autopilot capability
- Controller tuning
- Open source
- GCS interfacing
- Payload
- Endurance
- Cost/Availability

Resources (1/2)

- Thrust calculator:
  - http://www.gobrushless.com/testing/thrust_calculator.php
  - http://www.flybrushless.com/tools/thrustCalc
  - http://www.electricrcaircraftguy.com/2013/09/propeller-static-dynamic-thrust-equation.html
- Open source autopilot:
  - http://ardupilot.org/ardupilot/index.html
  - http://www.openpilot.org/
  - https://wiki.paparazziuav.org/wiki/Main_Page
  - http://aeroquad.com/content.php?s=07985f0ccb32fd617e2842cff718e976

Resources (2/2)

- Open source GCS:
  - http://www.qgroundcontrol.org/
- DIY:
  - http://www.robotshop.com/blog/en/robots/gorobotics/tutorials/how-to-make-a-drone-uav

Thank you ☺

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