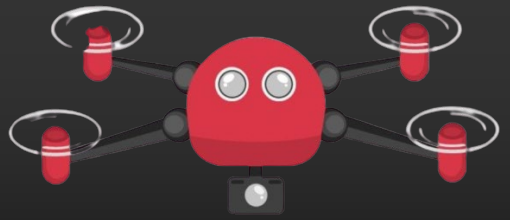


FlyOS : Integrated Modular Avionics for Autonomous Multicopters

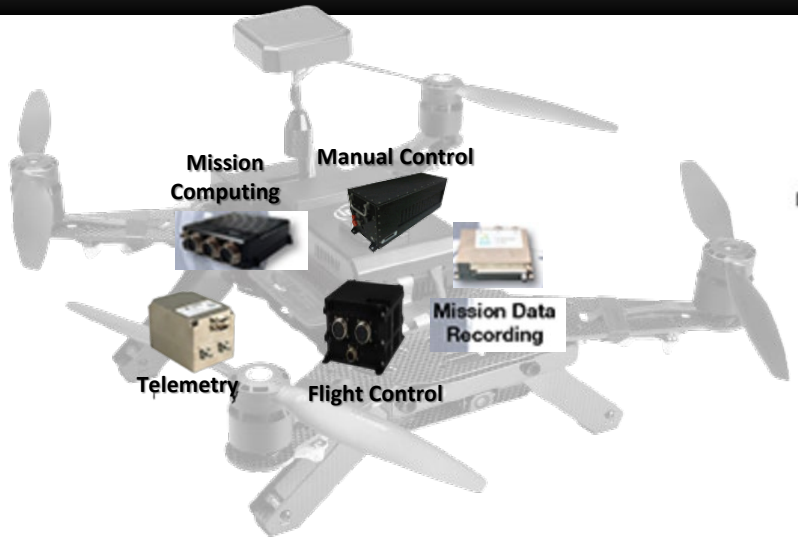
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Anam Farrukh

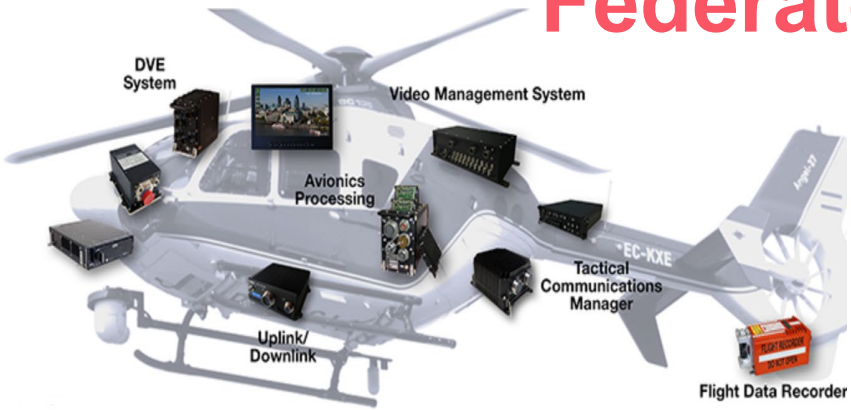
Richard West

BOSTON UNIVERSITY

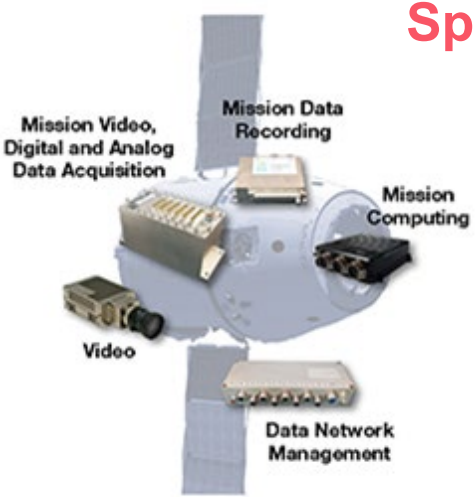
Federated Avionics

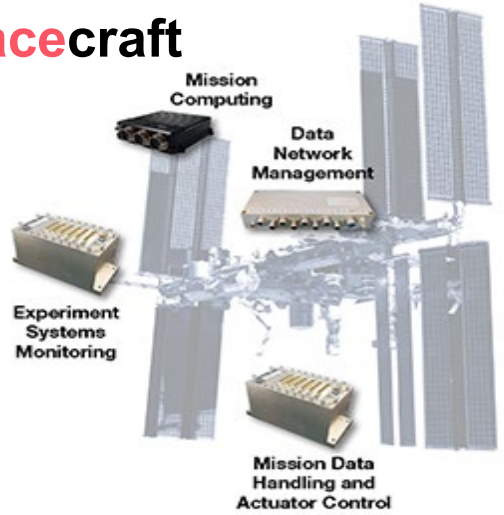


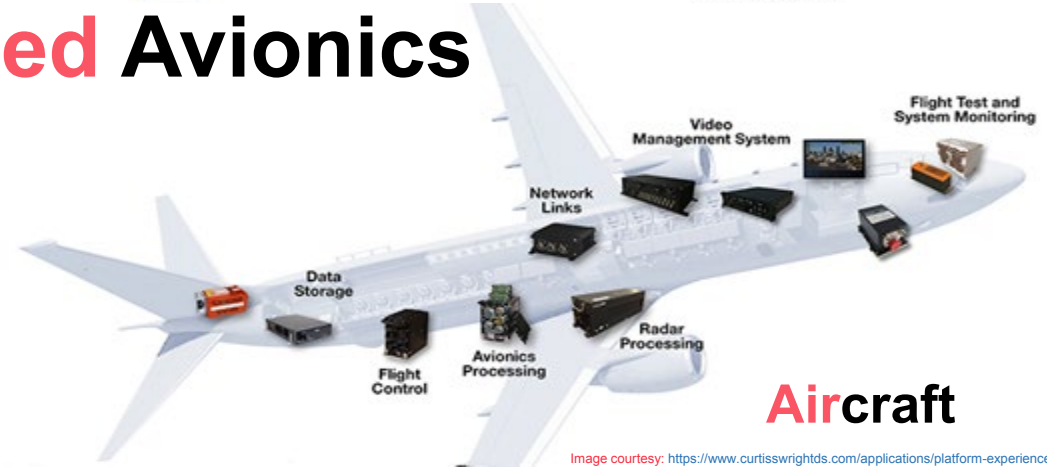
Rotorcraft



Spacecraft







Aircraft

Image courtesy: https://www.curtisswrightds.com/applications/platform-experience

Federated Avionics: Core Architecture

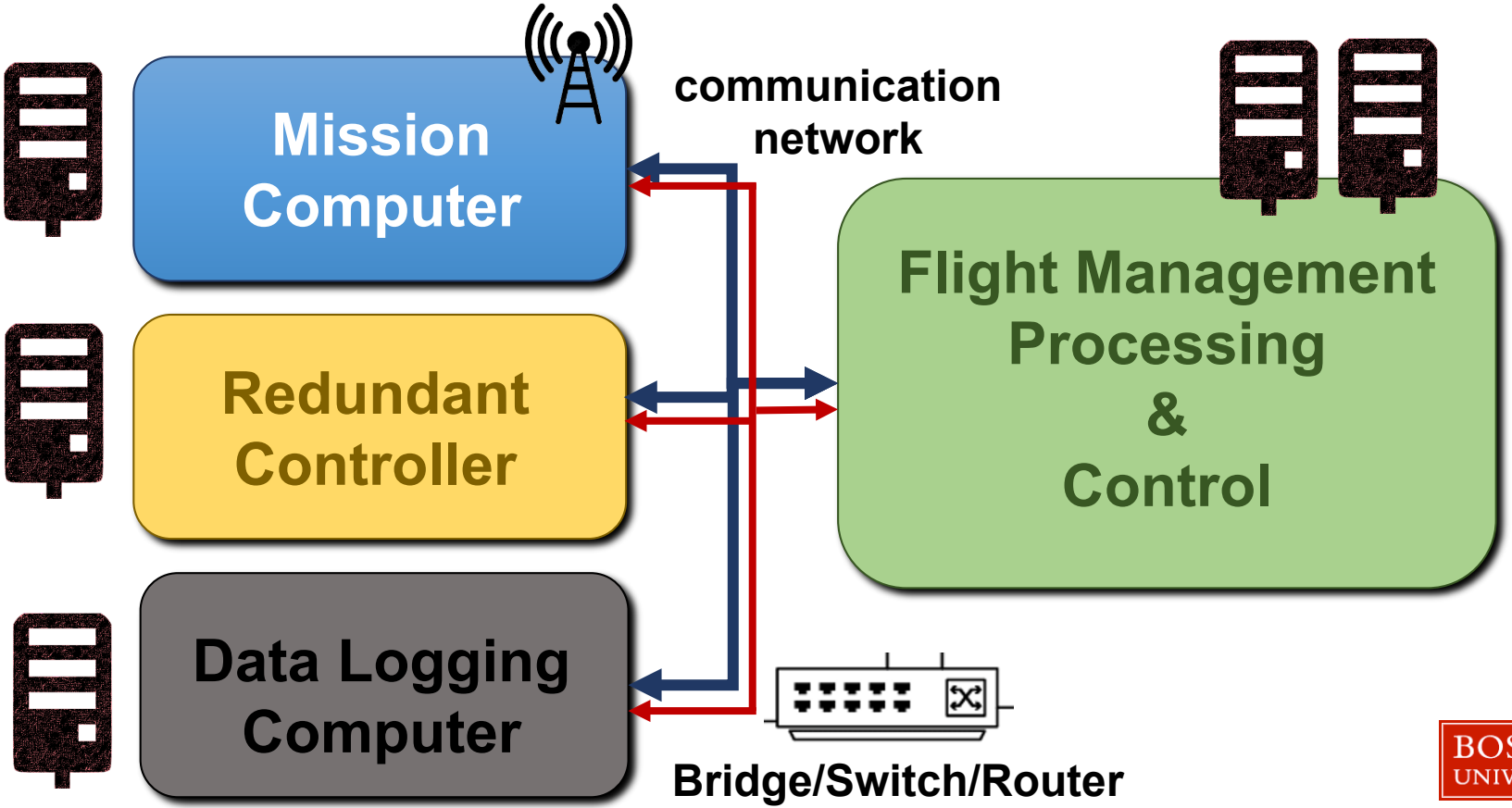


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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Federated Avionics: Challenges

- Communication costs
  - Limited reactivity to high-frequency changes to mission objectives

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Federated Avionics: Challenges

- Communication costs
  - Limited reactivity to high-frequency changes to mission objectives
- Software & hardware upgrade/replacement costs
  - Support for only simple & limited functionality

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Federated Avionics: Challenges

- Communication costs
  - Limited reactivity to high-frequency changes to mission objectives
- Software & hardware upgrade/replacement costs
  - Support for only simple & limited functionality
- Increased size, weight and power (SWaP)
  - Limits hardware + software redundancy

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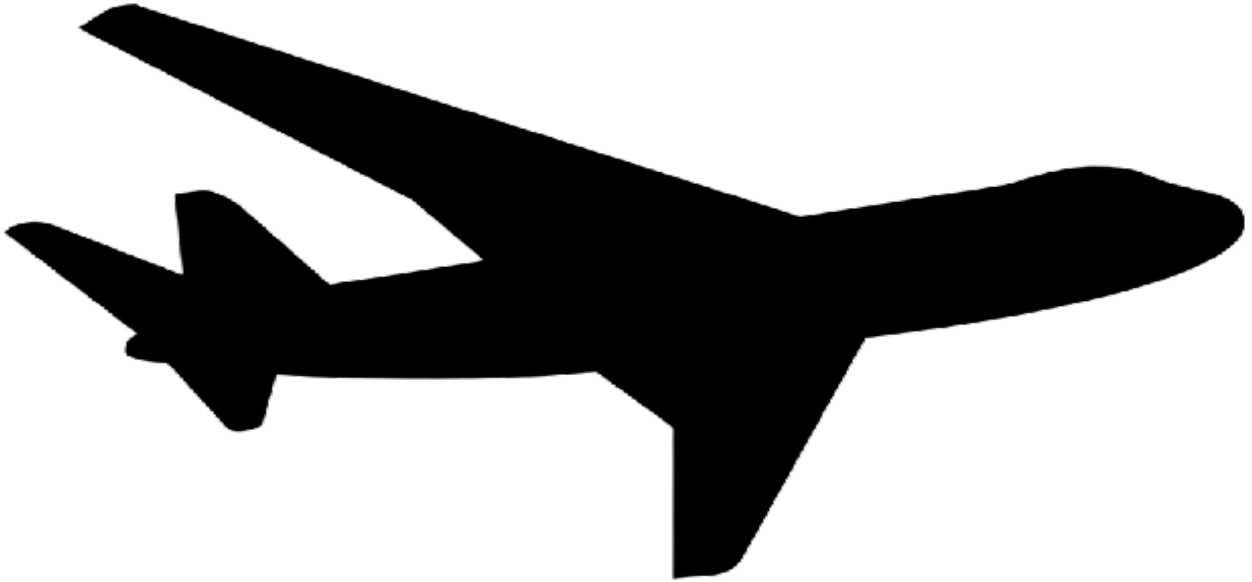
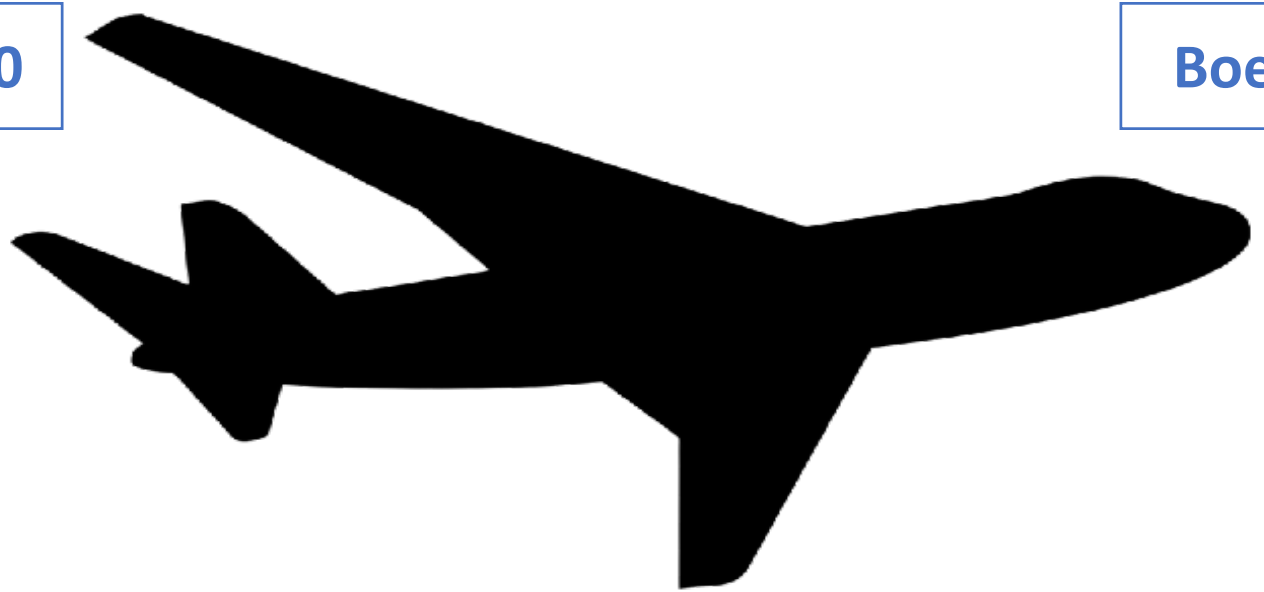
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

A step towards:
Integrated Modular Avionics



A step towards:
Integrated Modular Avionics

Airbus A380

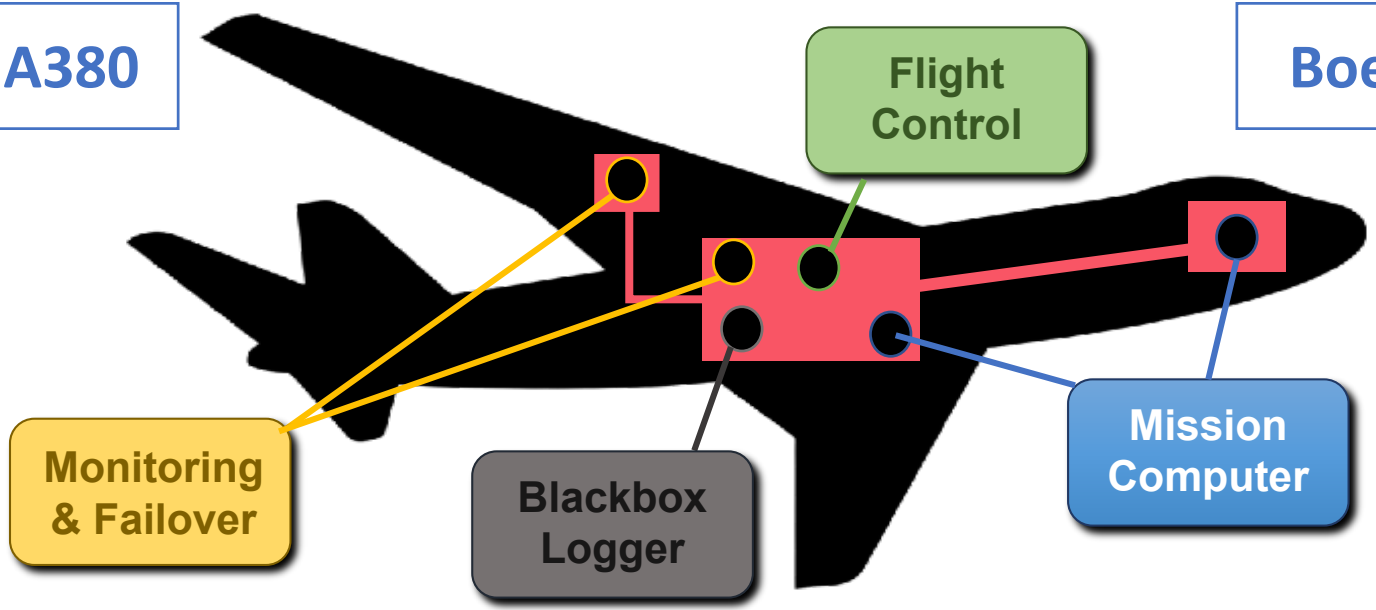


Boeing 787

A step towards:
Integrated Modular Avionics

Airbus A380

Boeing 787



Integrated Modular Avionics: Challenge

Isolation

Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Integrated Modular Avionics: Challenge

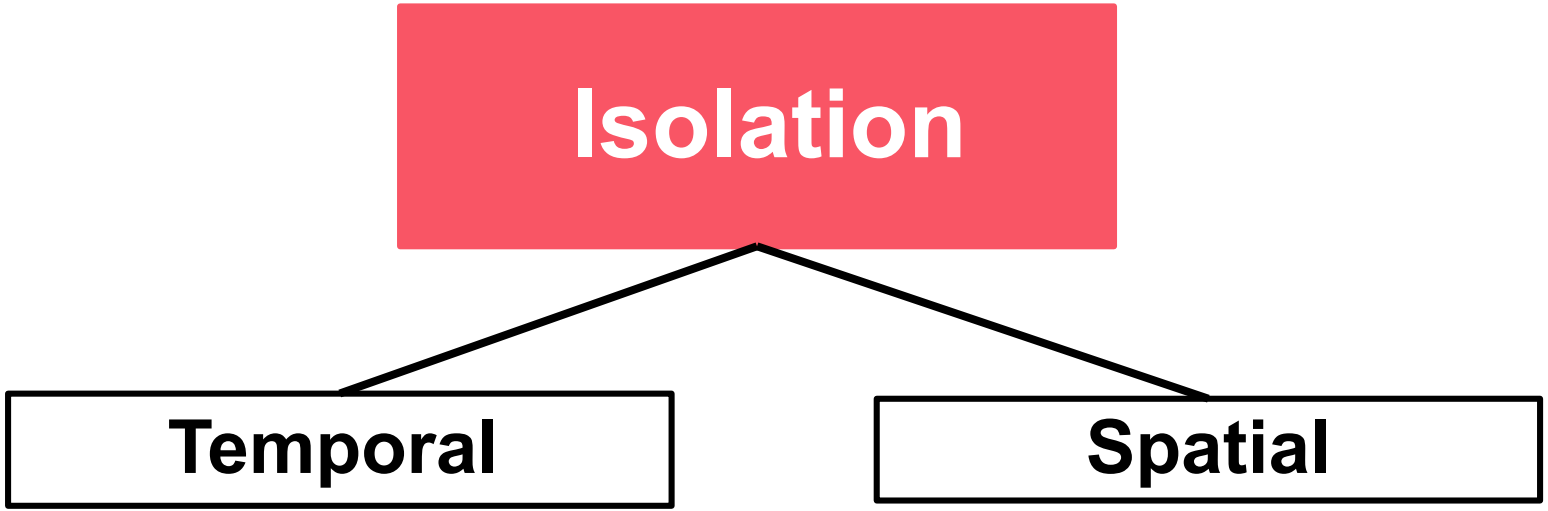


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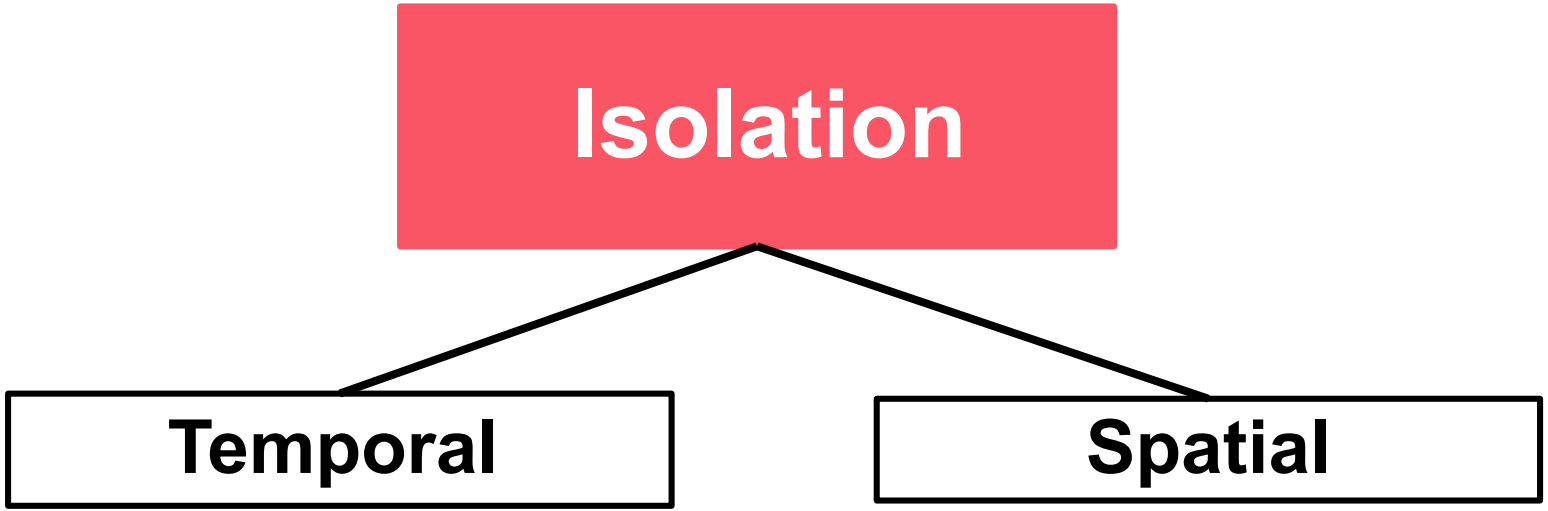
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Integrated Modular Avionics: Challenge



- Run-time Interference
  - Fault Propagation

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Integrated Avionics: Core Architecture

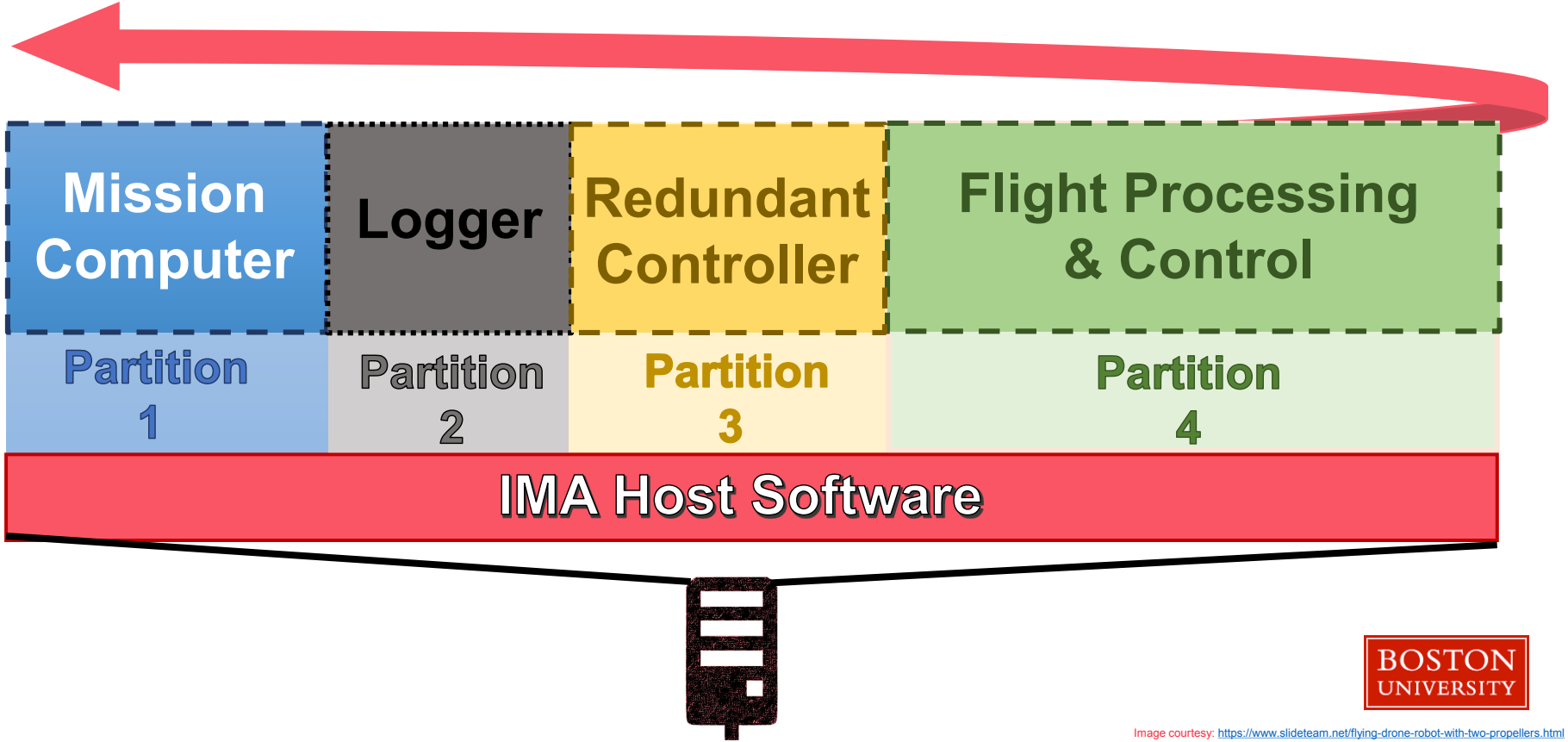

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Integrated Avionics: Core Architecture

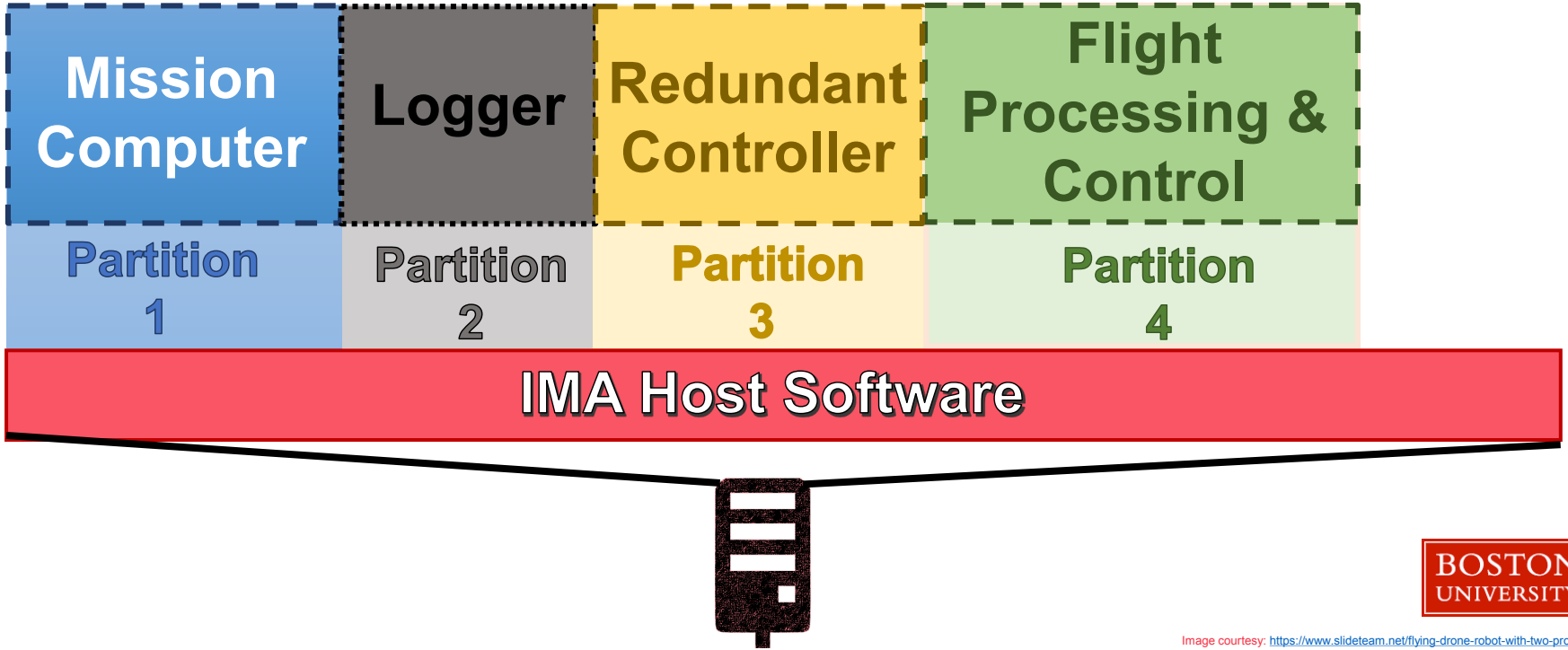

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Integrated Avionics: Core Architecture

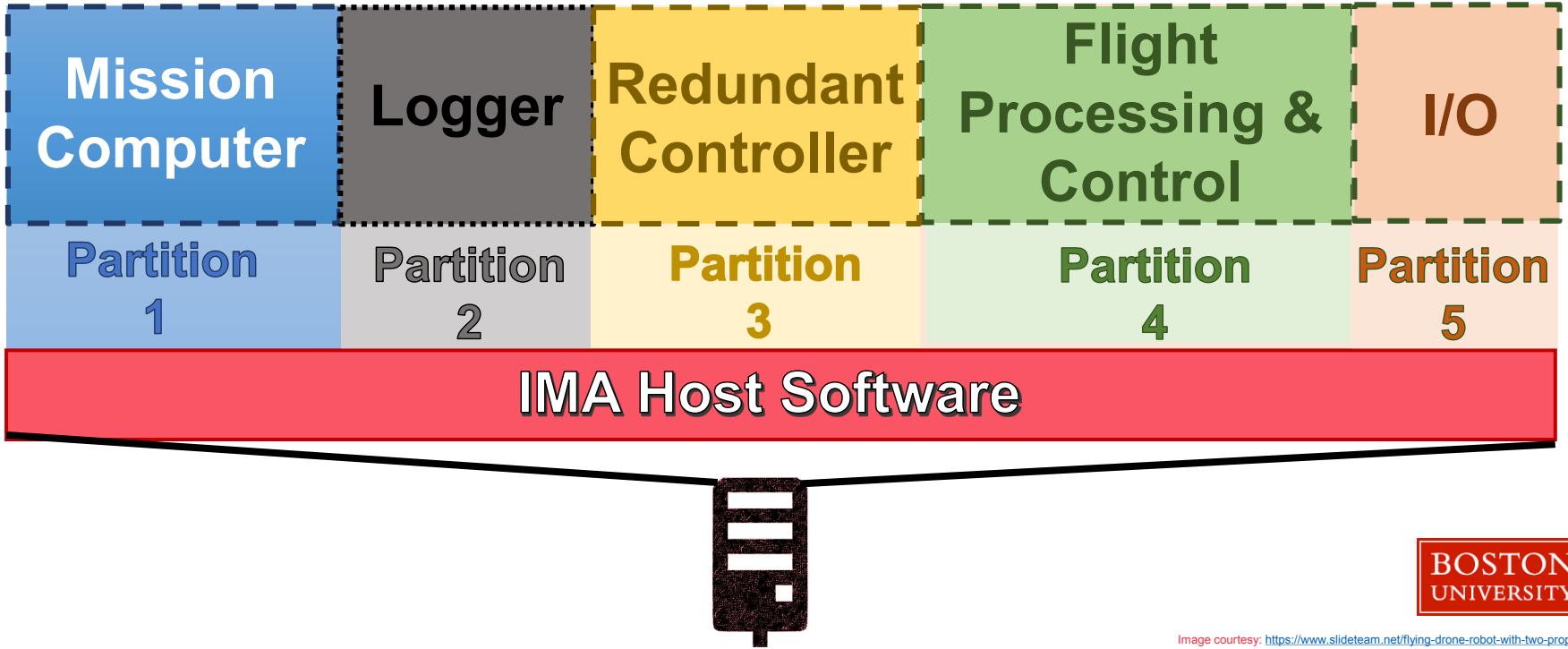

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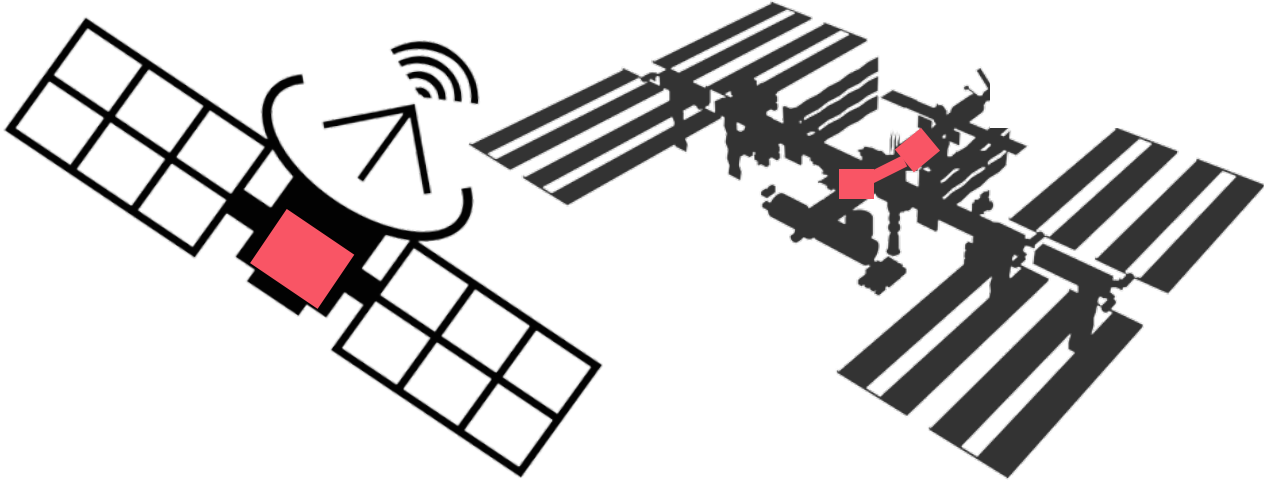
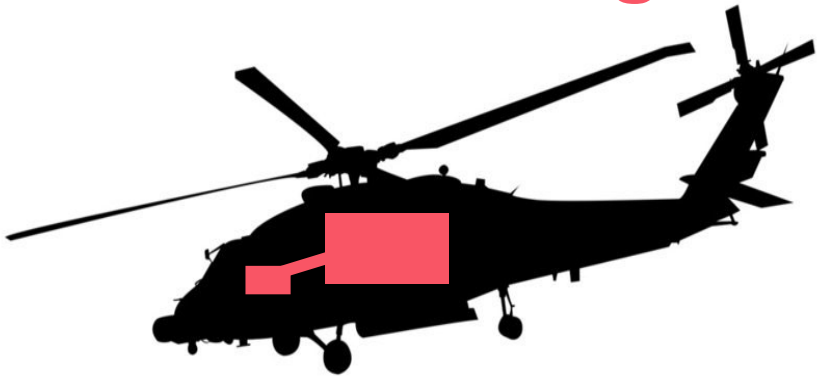
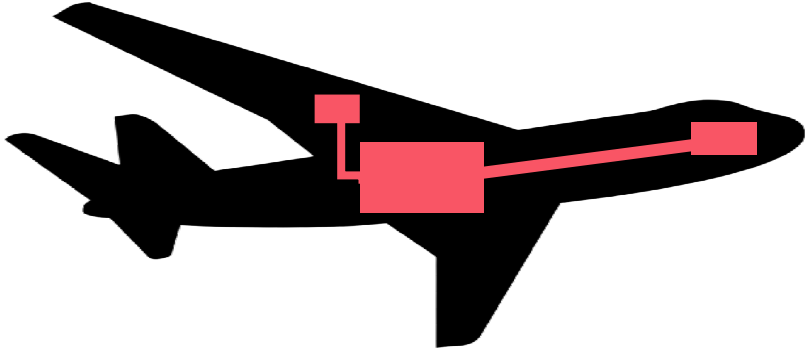
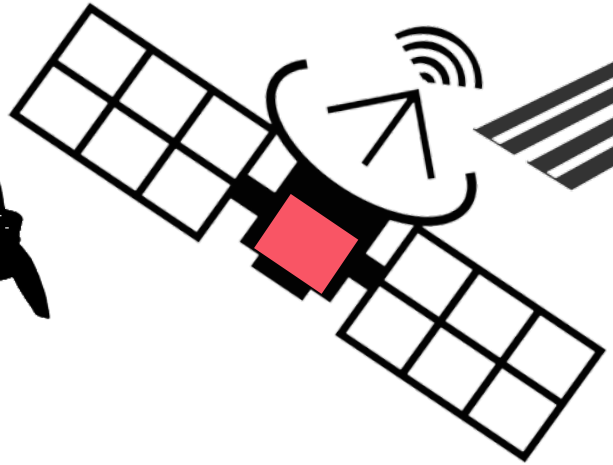
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

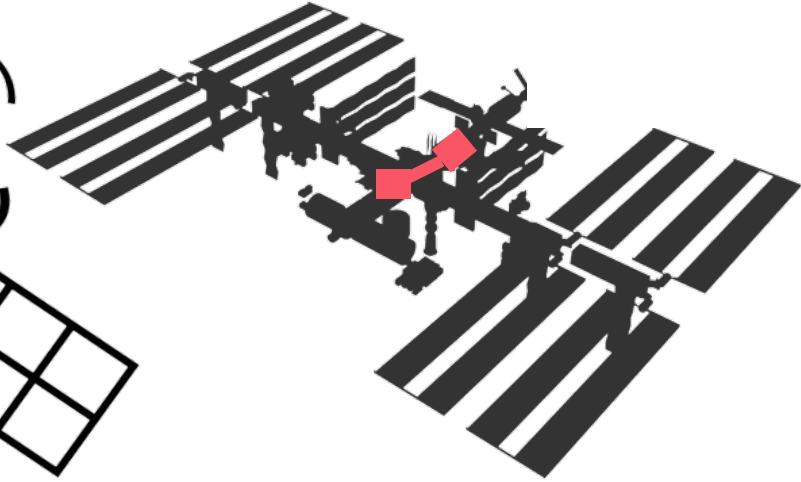


Integrated Modular Avionics

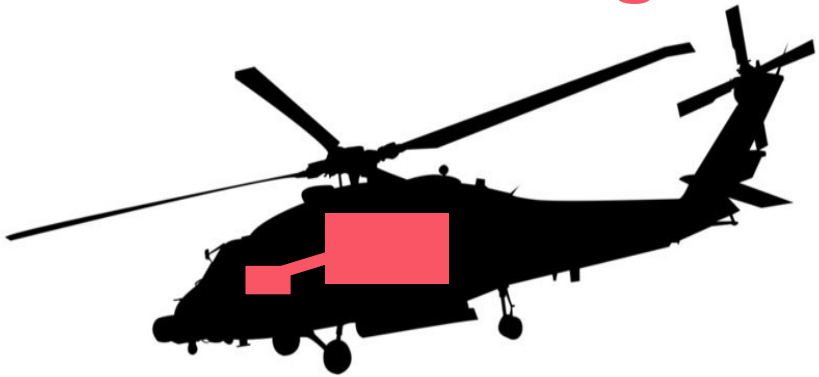


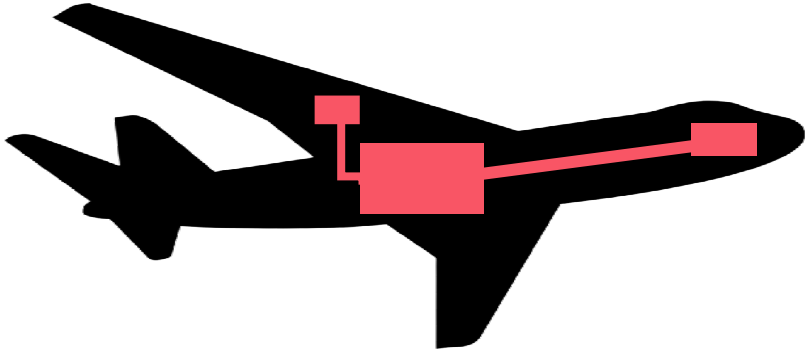


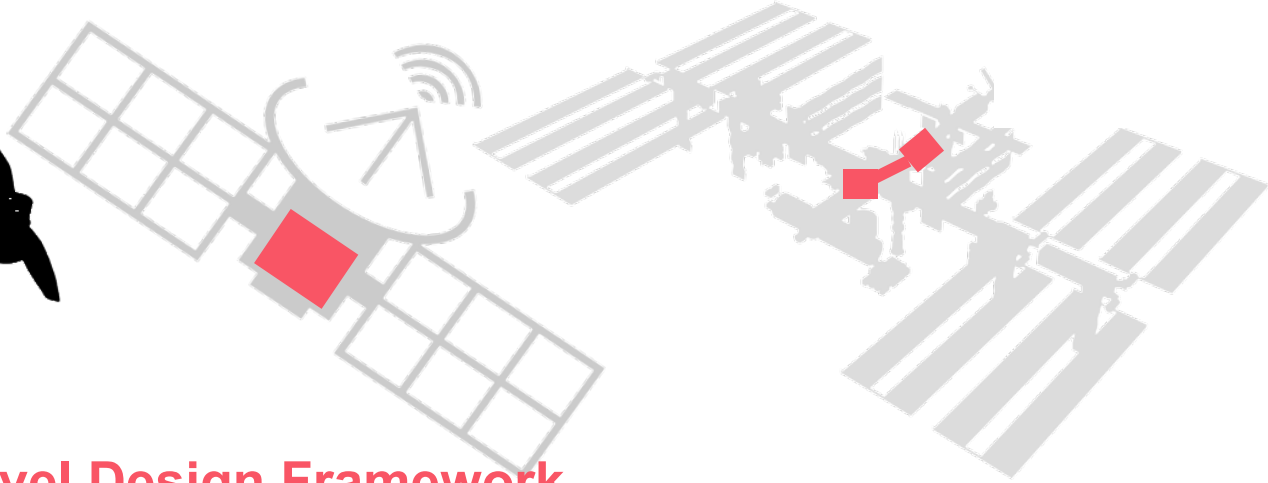




Integrated Modular Avionics

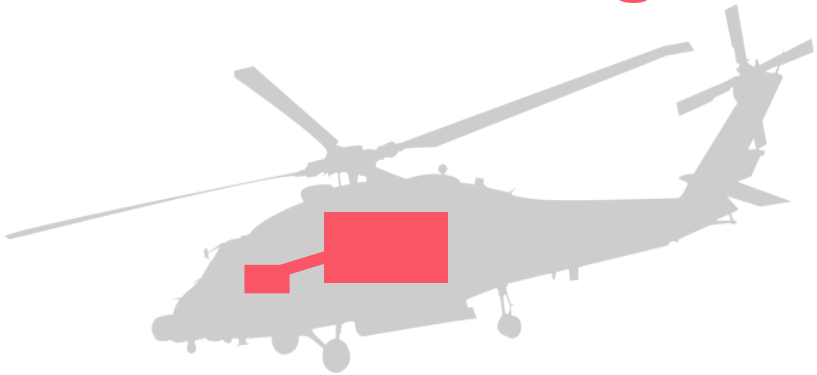


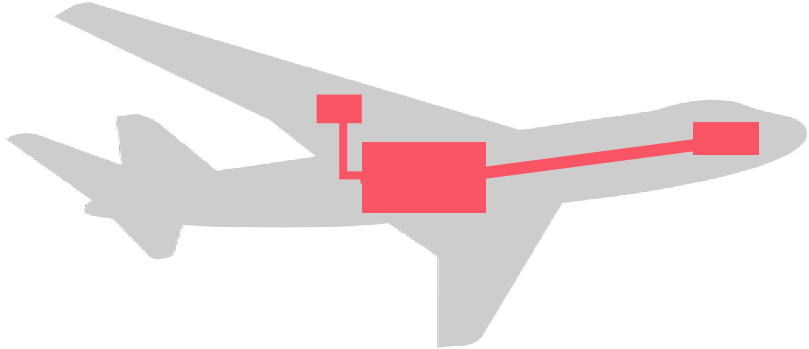




A Novel Design Framework

Integrated Modular Avionics





FlyOS: the IMA solution to Multicopter Avionics

Separation Kernel

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

FlyOS: the IMA solution to Multicopter Avionics

Distributed
System-on-a-Chip

Separation Kernel

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

FlyOS: the IMA solution to Multicopter Avionics

Distributed
System-on-a-Chip

Separation Kernel

Isolated
Regimes

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

FlyOS: the IMA solution to Multicopter Avionics

Distributed
System-on-a-Chip

Symbiotic
Coexistence

Separation Kernel

Isolated
Regimes

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

FlyOS: the IMA solution to Multicopter Avionics

Distributed
System-on-a-Chip

Symbiotic
Coexistence

Separation Kernel

Isolated
Regimes

Minimal
Trusted Compute Base

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

FlyOS: the IMA solution to Multicopter Avionics

Distributed
System-on-a-Chip

Symbiotic
Coexistence

Separation Kernel

Isolated
Regimes

Minimal
Trusted Compute Base

Explicit
Communication Channels

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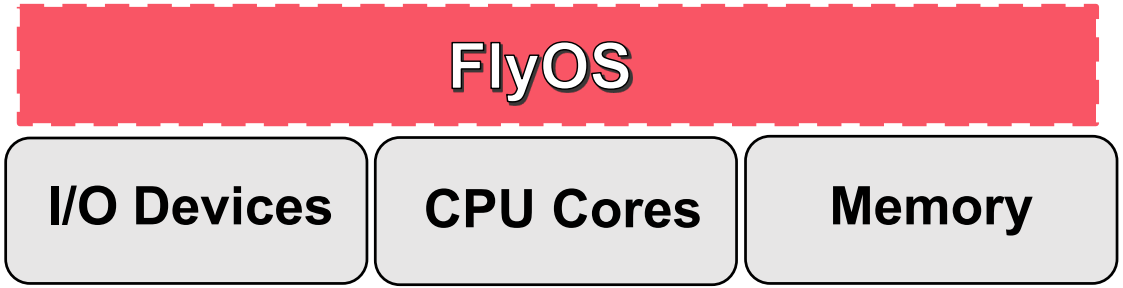
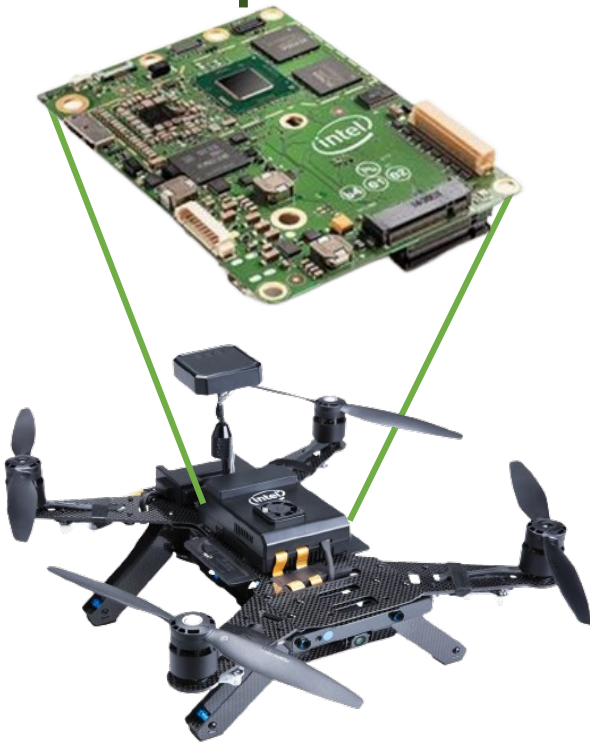
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

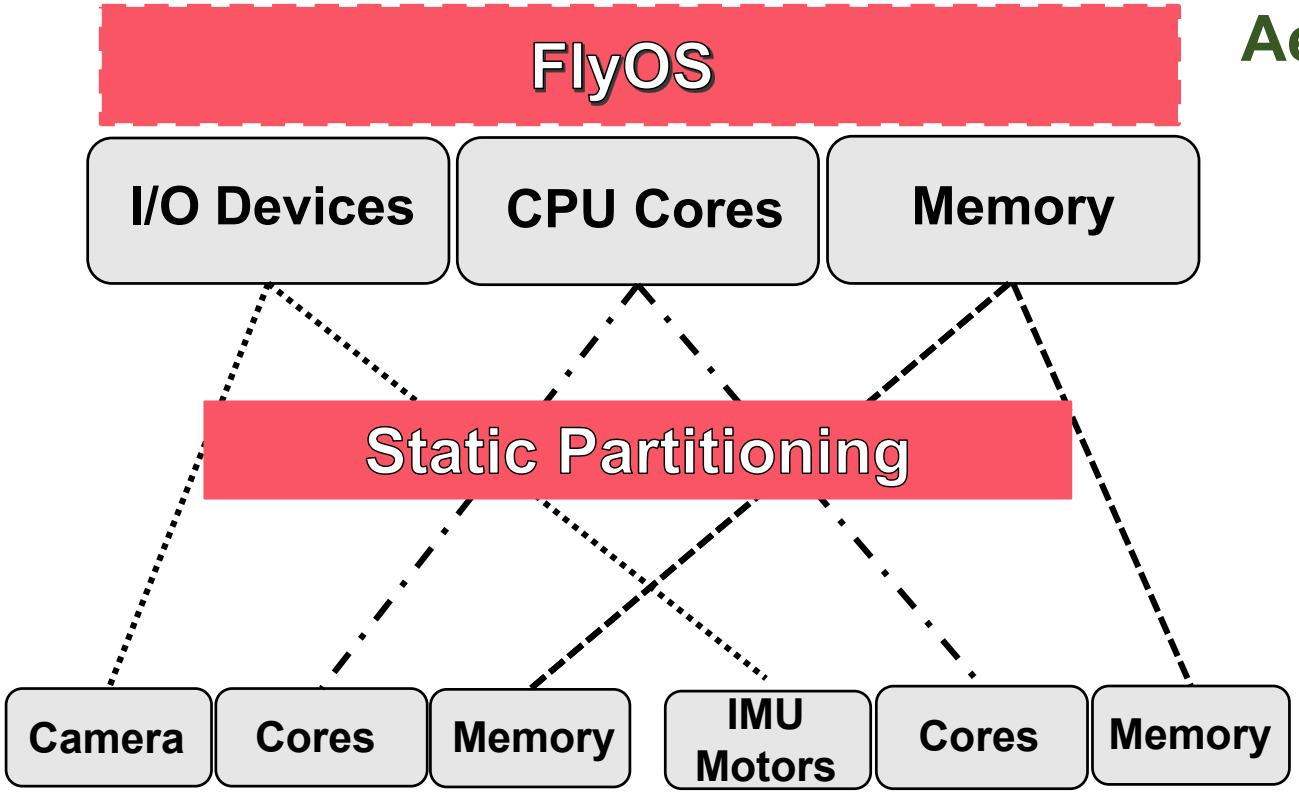
FlyOS Architecture: Partitioning Hypervisor



Aero Compute Board



FlyOS Architecture: Partitioning Hypervisor



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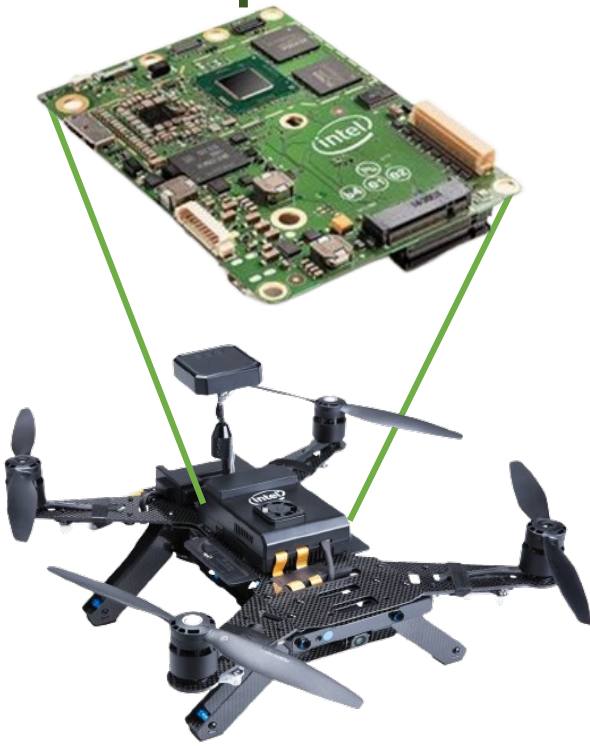

FlyOS Architecture: Partitioning Hypervisor

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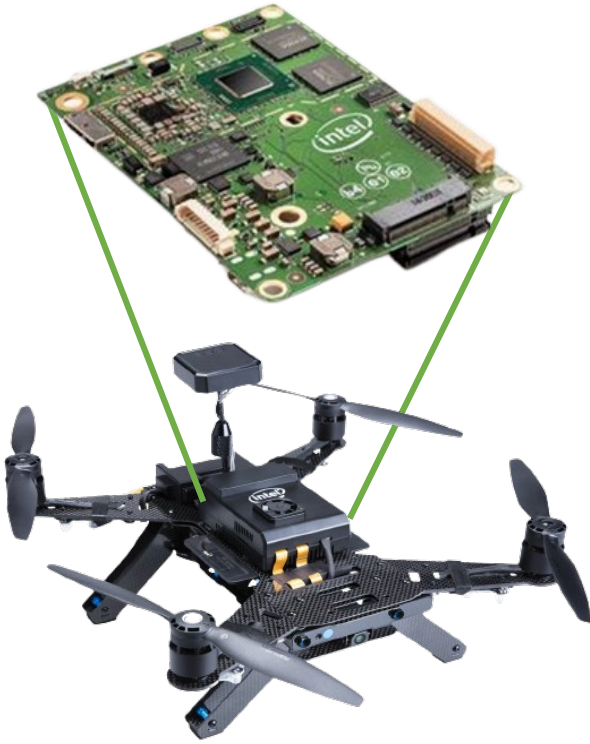


Quest

Real-Time Operating System

Userspace

Kernel

Monitor (VMM)

Camera	Cores	Memory	IMU Motors	Cores	Memory

FlyOS Architecture: Partitioning Hypervisor

Linux
General Purpose Operating System

Userspace

Kernel

Monitor (VMM)

Quest
Real-Time Operating System

Lockless Communication

Userspace

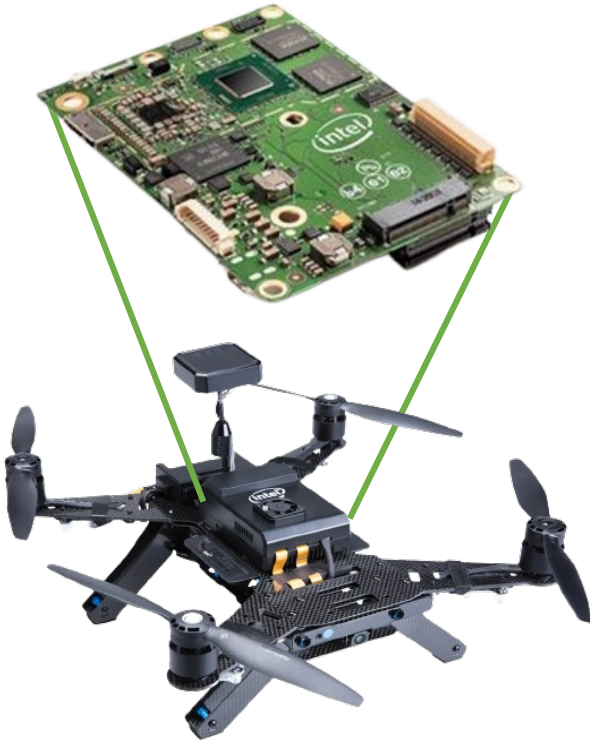
Kernel

Monitor (VMM)

Camera | Cores | Memory

IMU Motors | Cores | Memory

Aero Board



FlyOS Architecture: Partitioning Hypervisor

Sandbox

Linux

General Purpose Operating System

Mission Critical

Userspace

Kernel

Monitor (VMM)

Camera | Cores | Memory

Sandbox

Quest

Real-Time Operating System

Timing & Safety Critical

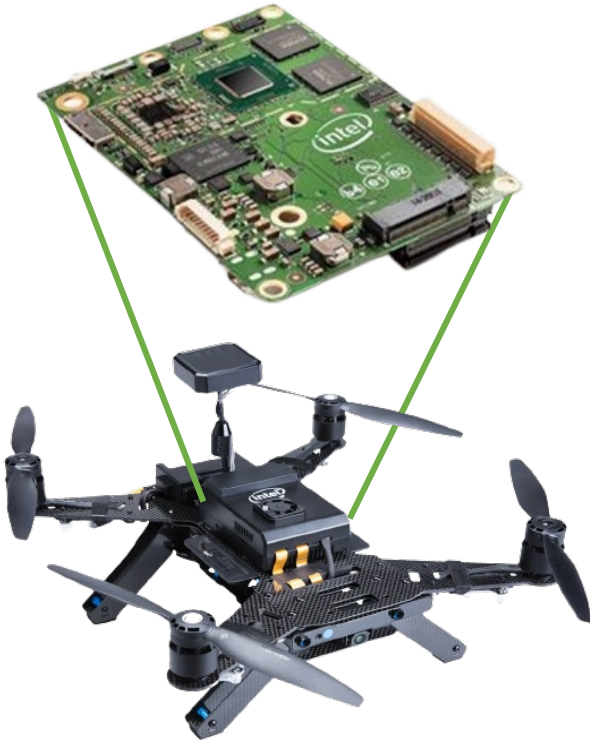
Userspace

Kernel

Monitor (VMM)

IMU Motors | Cores | Memory

Aero Board



FlyOS Architecture: Partitioning Hypervisor

Linux Sandbox

Quest Sandbox

Logger

Redundant Controller

Mission Computer

Flight Processing & Control

Linux GPOS Kernel

Monitor (VMM)

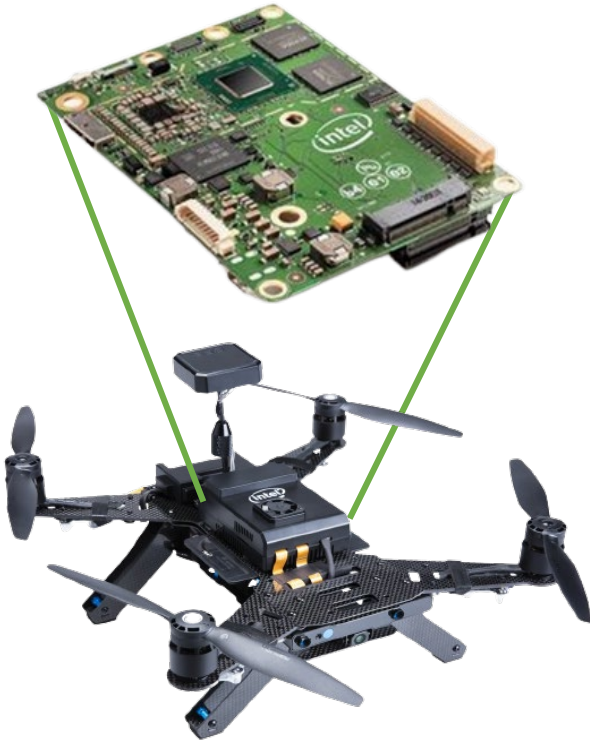
Quest RTOS Kernel

Monitor (VMM)

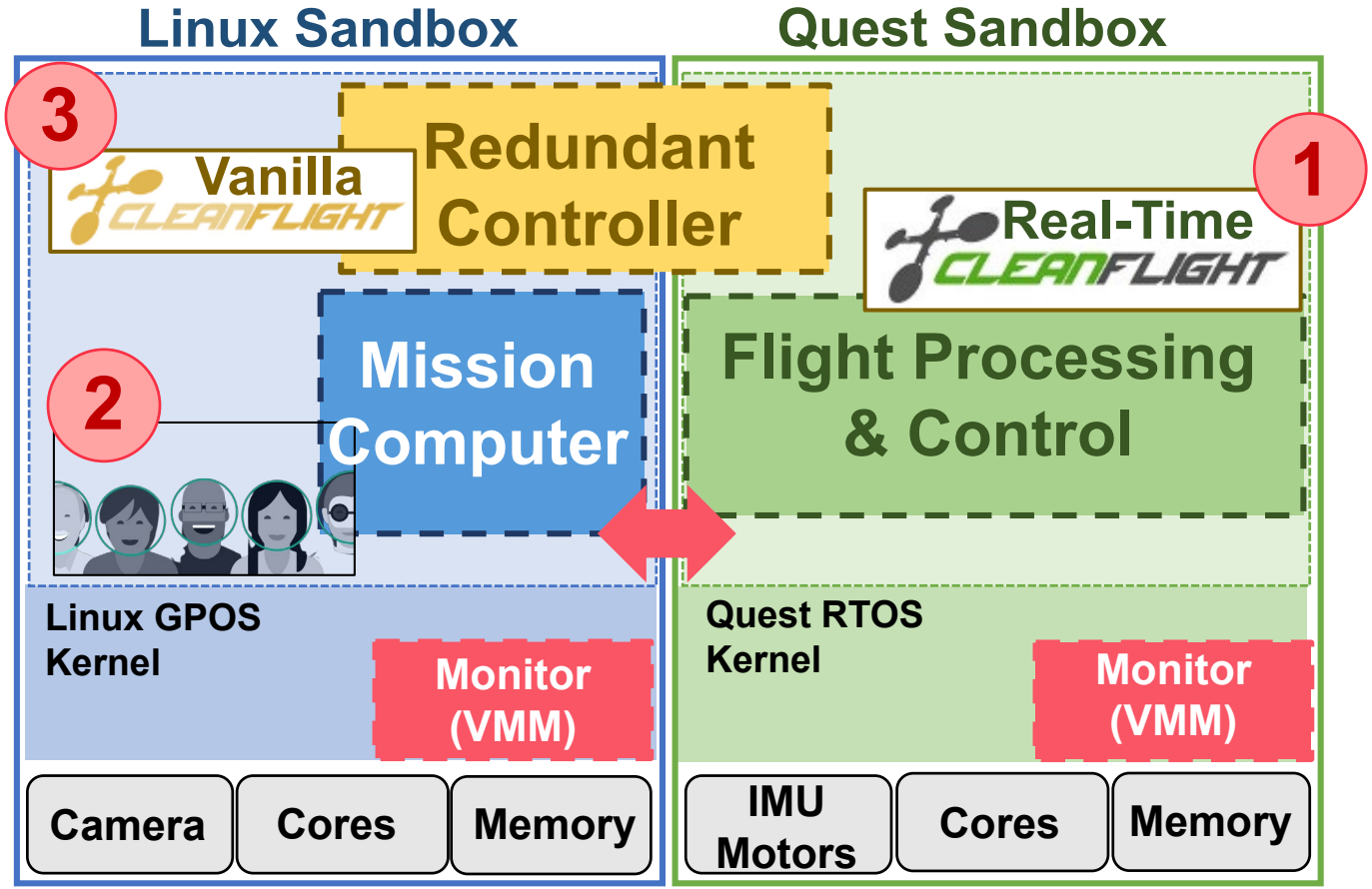
Camera | Cores | Memory

IMU Motors | Cores | Memory

Aero Board



FlyOS Architecture: Avionic Functions



Avionic Functions

1

Real-Time Flight Management System (Autopilot)

Sensing → Processing + Control → Actuation

CLEANFLIGHT

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Avionic Functions

1 Real-Time Flight Management System (Autopilot)

Pipe-1 — Intra-Sandbox (Quest)

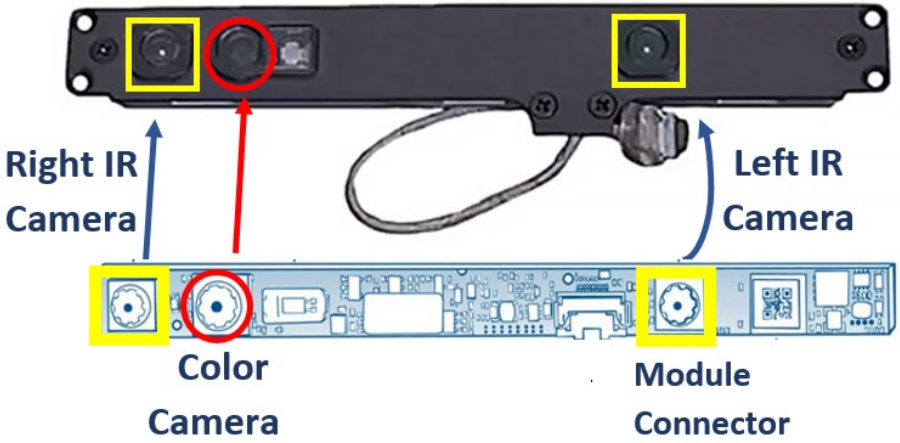
IMU → Attitude Calculation → PID + Mixer → Motors

Pipe-2 — Inter-Sandbox (Linux + Quest)

Mission → RX → PID + Mixer → Motors

Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

2 Autonomous Mission Control



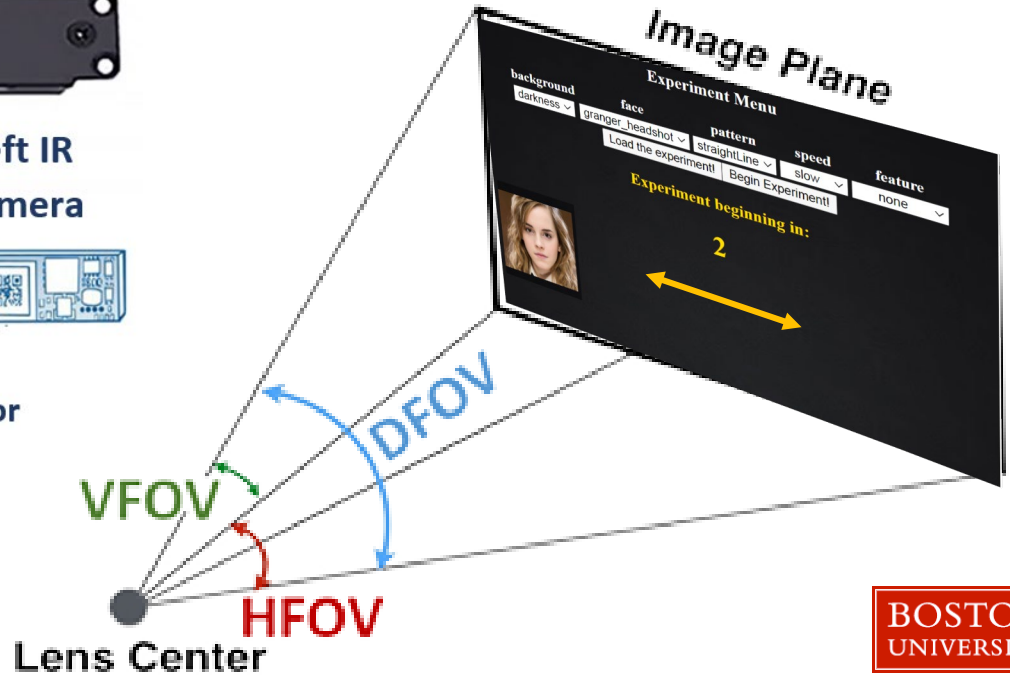


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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

2 Autonomous Mission Control

USB

Vision Subsystem: Face Detection

Capture Frame → Detect Face → Compute Error Distance

V4L2 (UVC Driver)

librealsense

OpenCV

Tracking

Determine SBUS Commands

De-project pixels (px,py) to 3D world point (x,y,z)

Logging

ASYNC

Pipe Buffer

Linux Sandbox

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

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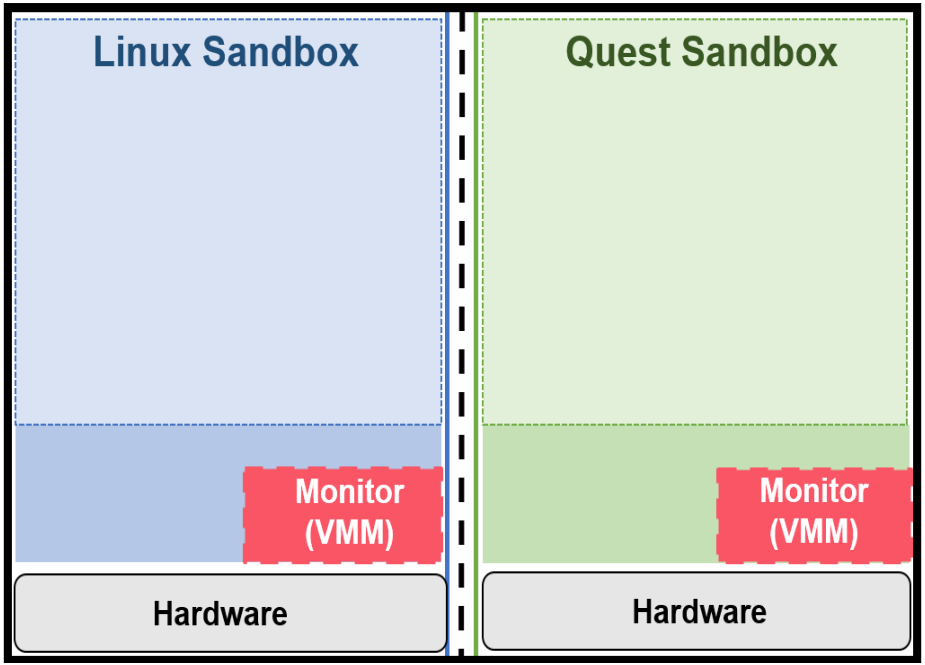
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

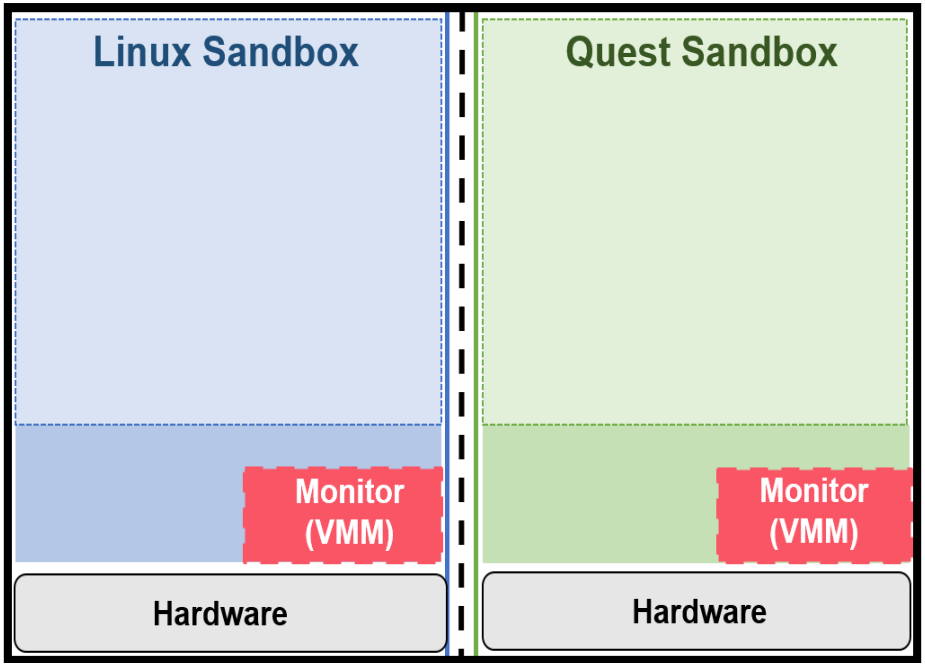
Software Redundancy:

- Sandboxed Architecture -



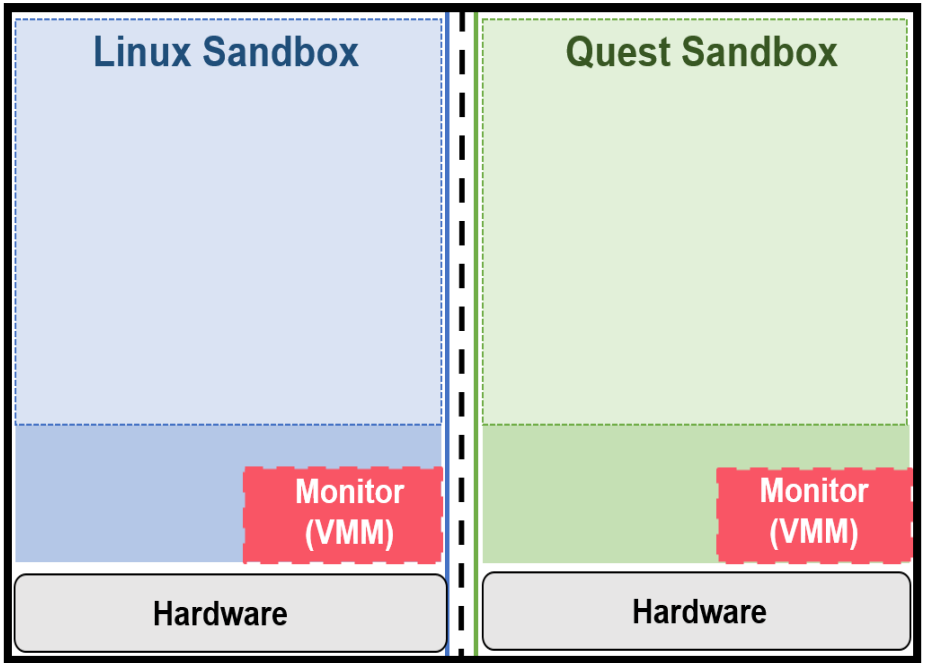
Software Redundancy:

- Sandboxed Architecture - **Fault Isolation**



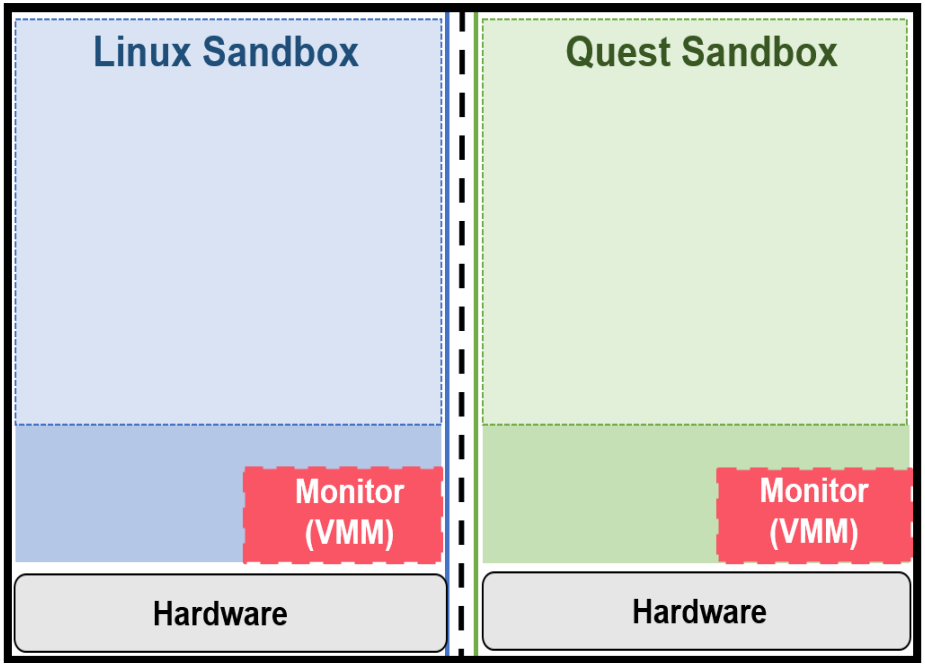
Software Redundancy: Fault-Tolerance

- Sandboxed Architecture - **Fault Isolation**



Software Redundancy: Fault-Tolerance

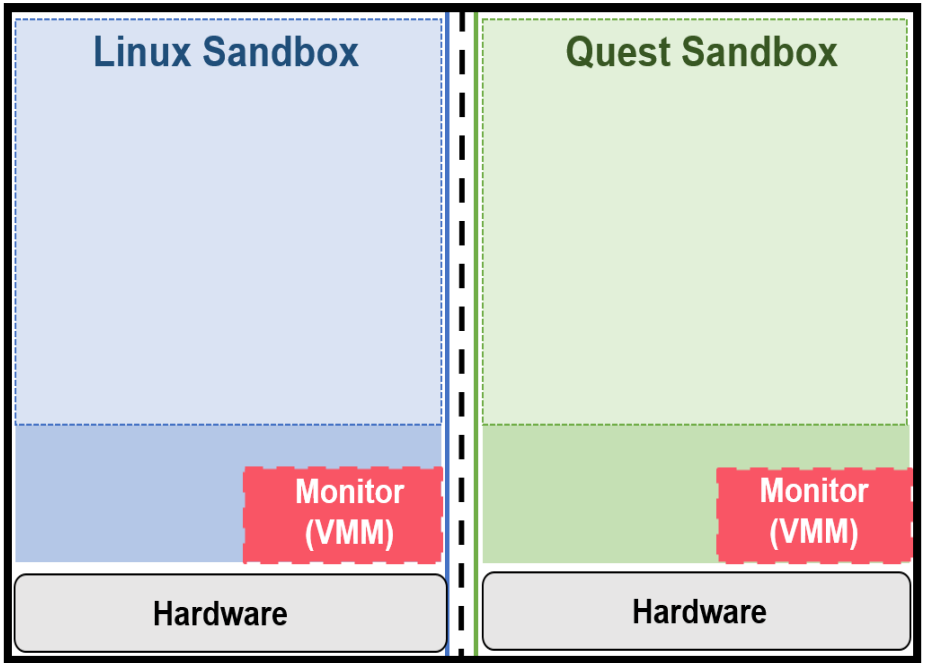
- Sandboxed Architecture - **Fault Isolation**



Failure Detection

Software Redundancy: Fault-Tolerance

- Sandboxed Architecture - **Fault Isolation**

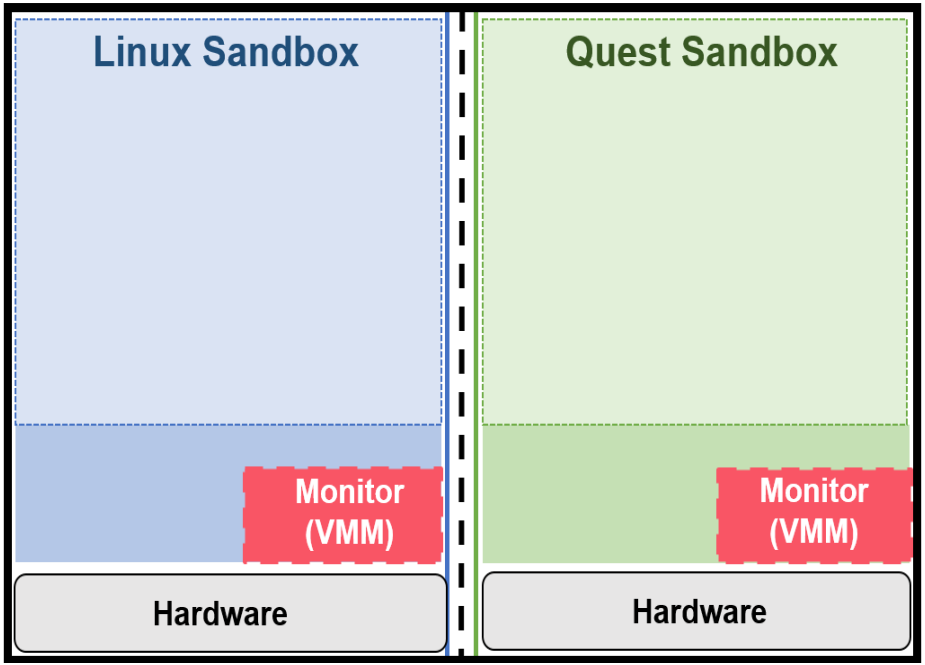


Failure Detection

Fail-Over Control

Software Redundancy: Fault-Tolerance

- Sandboxed Architecture - **Fault Isolation**



Failure Detection

Fail-Over Control

Fault Recovery

Software Redundancy: Fault-Tolerance

- Application-level
- Sandbox-level

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Software Redundancy: Fault-Tolerance

Application-level

Sandbox-level

- Function OR Timing faults
- Application redundancy
- Hot Standby activation

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Software Redundancy: Fault-Tolerance

Application-level

- Function OR Timing faults
- Application redundancy
- Hot Standby activation

Sandbox-level

- Kernel OR entire System faults
- Guest redundancy – local VMM
- Replica coordination
- Device-handoff

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

Software Redundancy: Fault-Tolerance

Application-level

- Function OR Timing faults
- Application redundancy
- Hot Standby activation

Sandbox-le

On-going Work

- OR entire System faults
- Guest redundancy – local VMM
- Replica coordination
- Device-handoff

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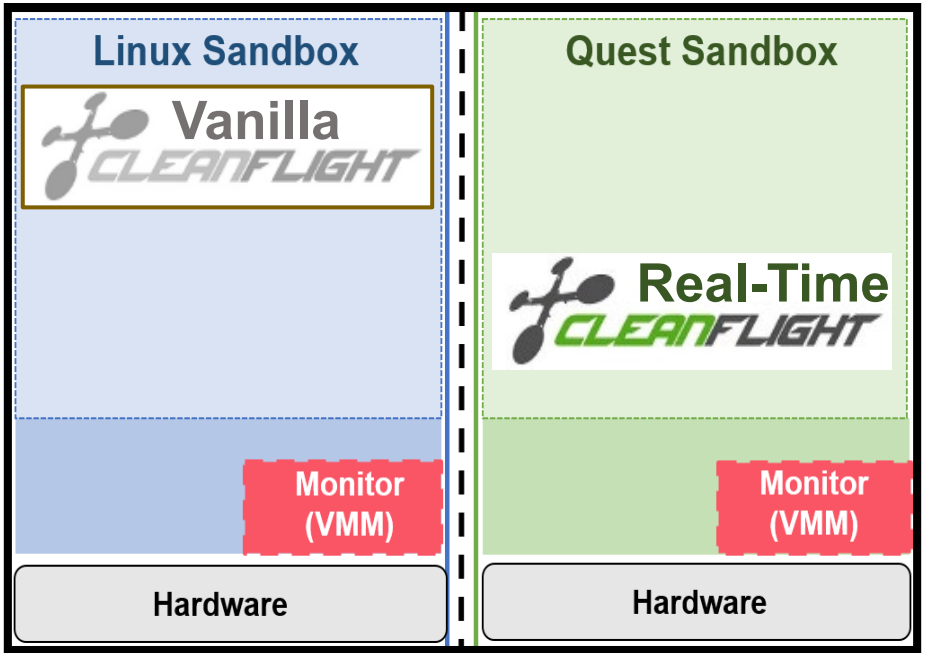
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

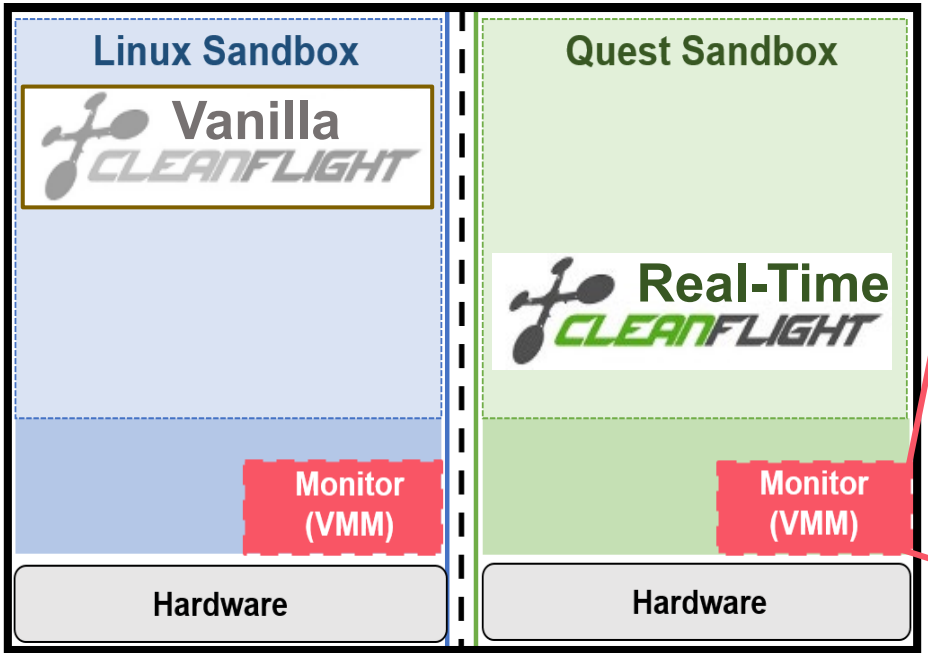
Fault-Tolerance Subsystem: Application

3 Flight Control Redundancy



Fault-Tolerance Subsystem: Application

3 Flight Control Redundancy



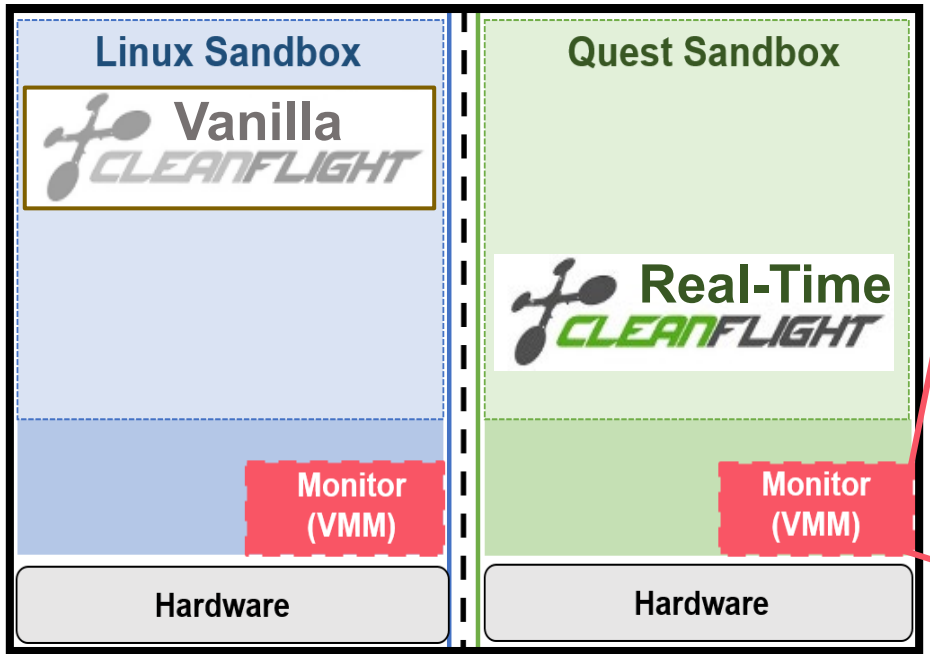
1

VMX Pre-emption Timer EXPIRES!

FlyOS: Monitor

Fault-Tolerance Subsystem: Application

3 Flight Control Redundancy



VMX Pre-emption Timer EXPIRES!

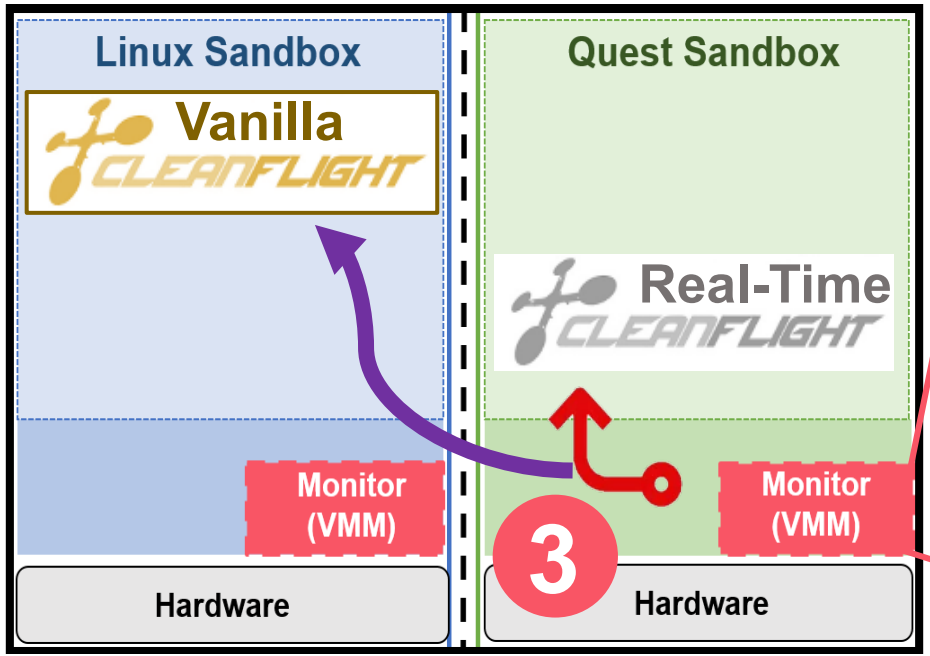
2

FAILSAFE MODE

FlyOS: Monitor

Fault-Tolerance Subsystem: Application

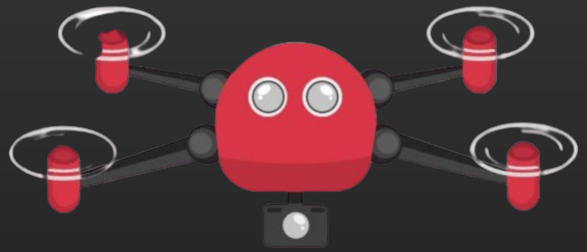
3 Flight Control Redundancy



VMX Pre-emption Timer EXPIRES!

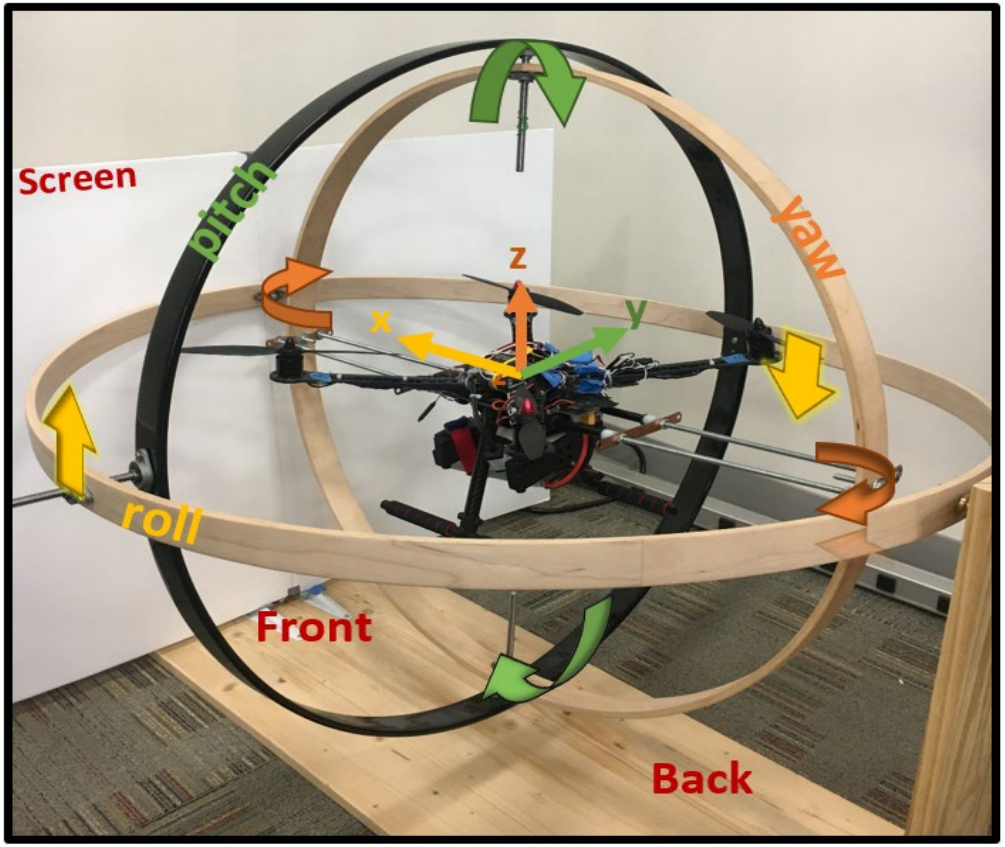
FAILSAFE MODE

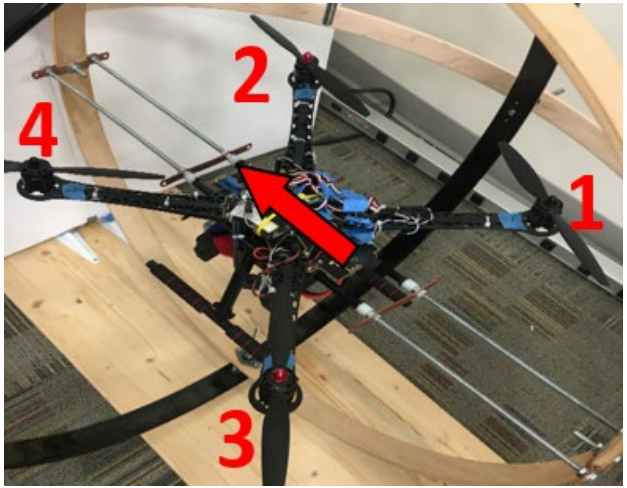
FlyOS: Monitor



FlyOS
Evaluation

BirdCage : Hardware-In-the-Loop Setup





The Bird

S500 Quadcopter Frame

FlyOS : Experimental Scenarios

I
Manual

Attitude Stabilization with an External Disturbance

II
Autonomous

Face-image Detection (static) & Tracking (moving)

III
Failover

Recover Stable Flight after a Motor fault

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

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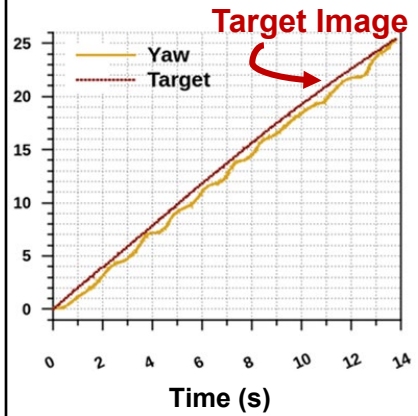
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

II : Autonomous Tracking



Yaw Right

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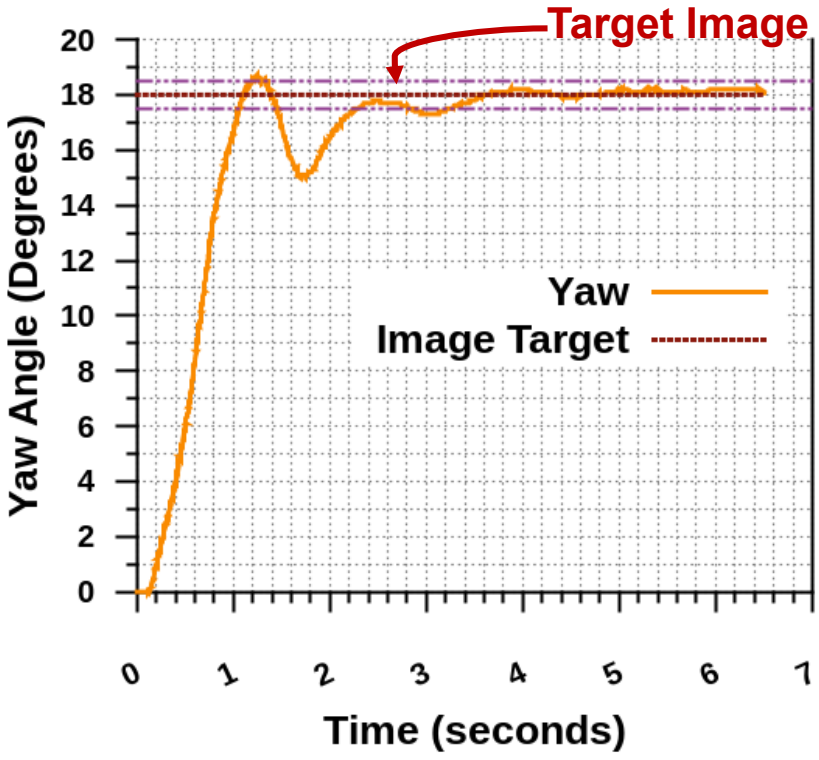
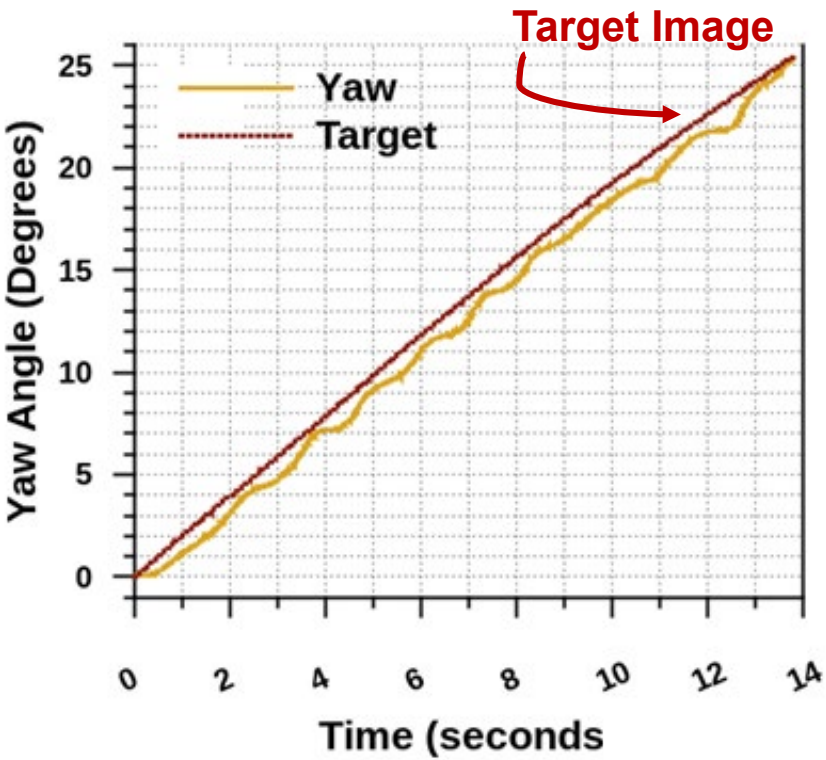
https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

II : Autonomous Detection & Tracking





Stationary Image

Yaw Right

Moving Image

FlyOS : Experimental Scenarios

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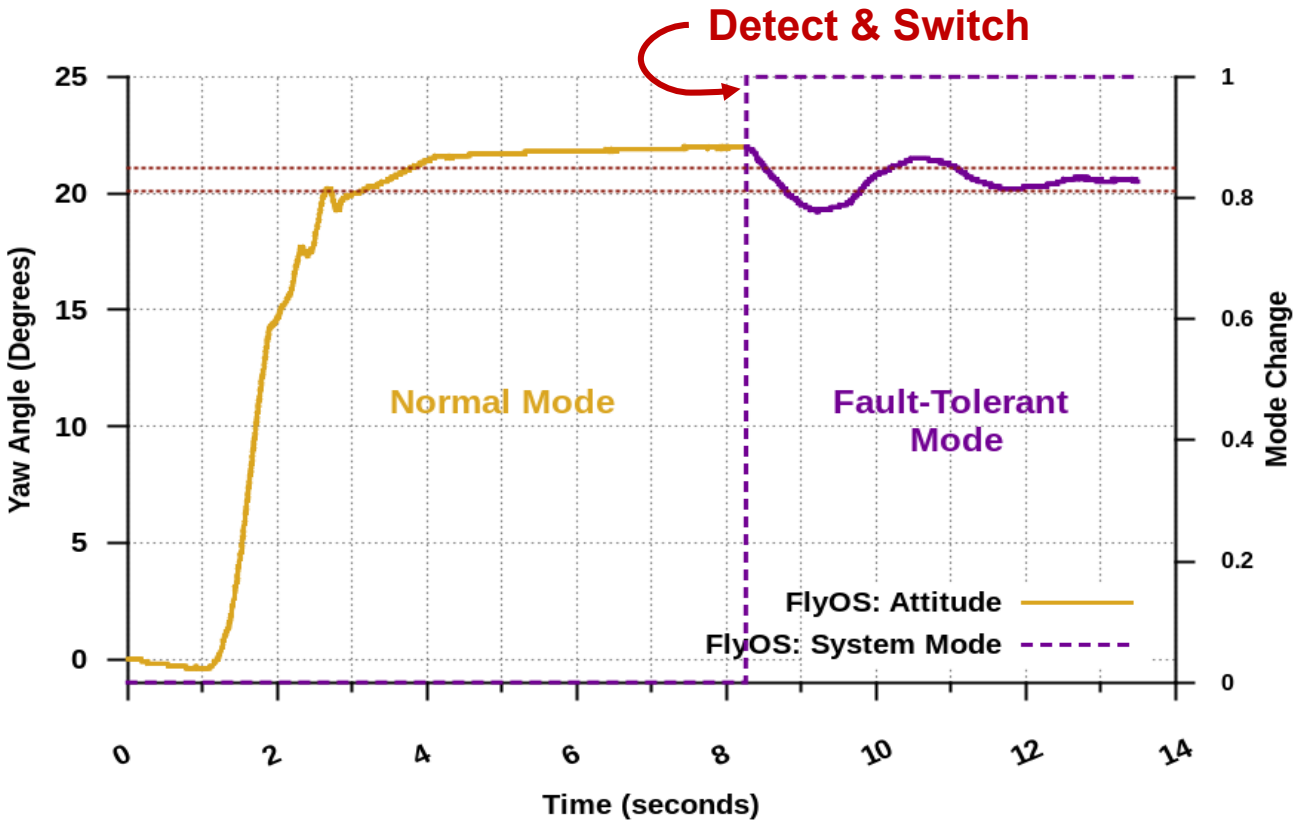
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

III : Failover Control

- Stale motor updates
- Stall Heartbeat
- Activate Hover-in-place



FlyOS: A Novel Framework

Integrated Modular Avionics (IMA) for Multicopters

Separation-Kernel

Partitioning Hypervisor

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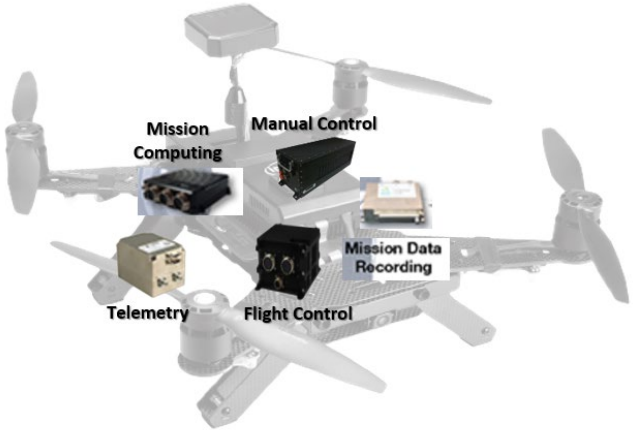
Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html

FlyOS: A Novel Framework

Integrated Modular Avionics (IMA) for Multicopters

Separation-Kernel **Partitioning Hypervisor**



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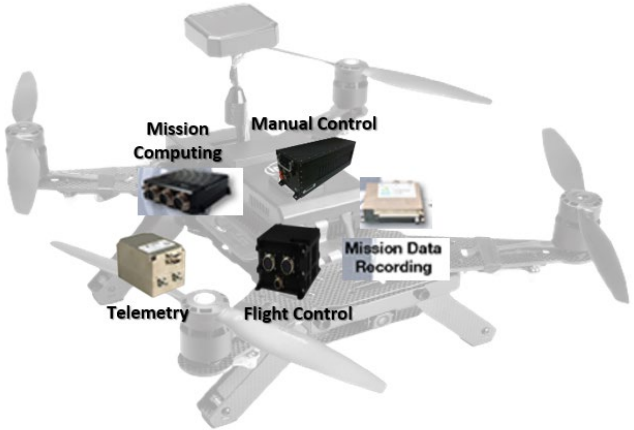
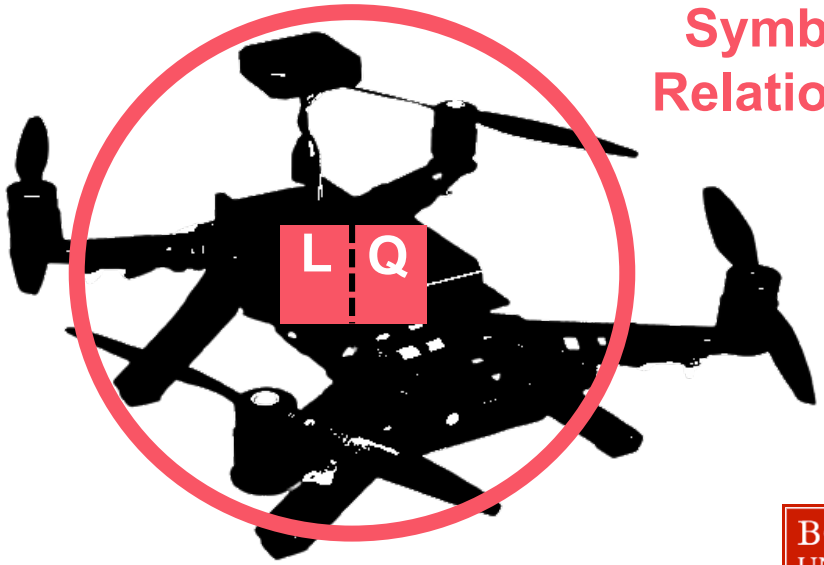
Separation-Kernel — **Partitioning Hypervisor**





Symbiotic Relationship

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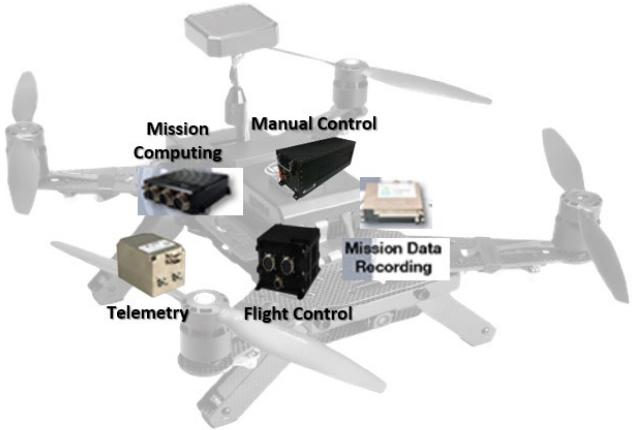
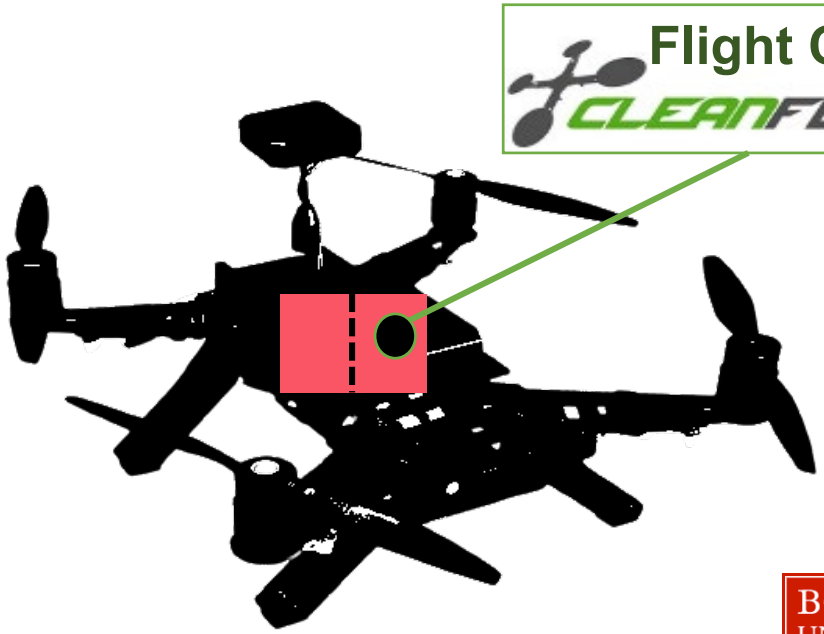
Separation-Kernel — **Partitioning Hypervisor**





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Integrated Modular Avionics (IMA) for Multicopters

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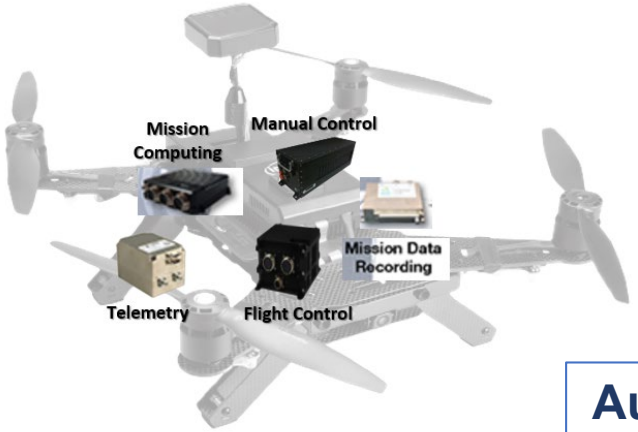
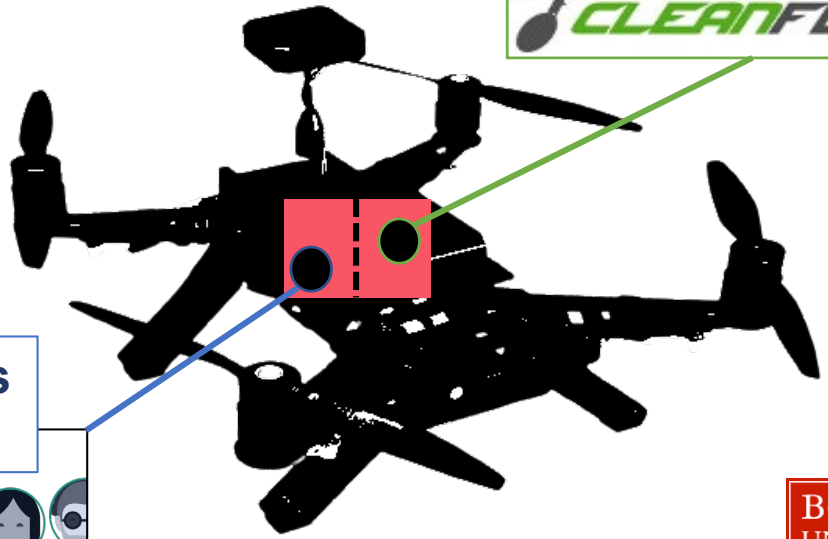


Flight Control

CLEANFLIGHT



Autonomous Mission

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FlyOS: A Novel Framework

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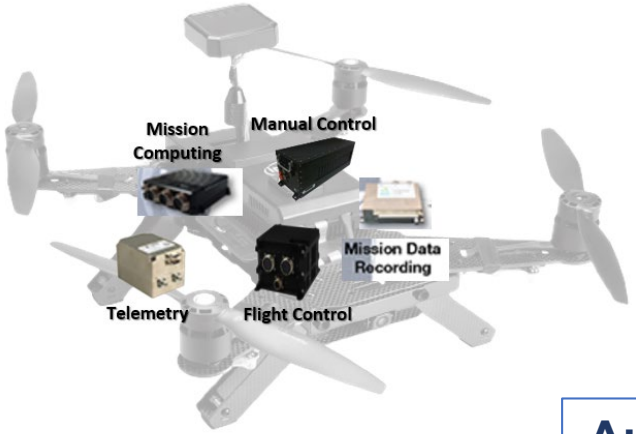
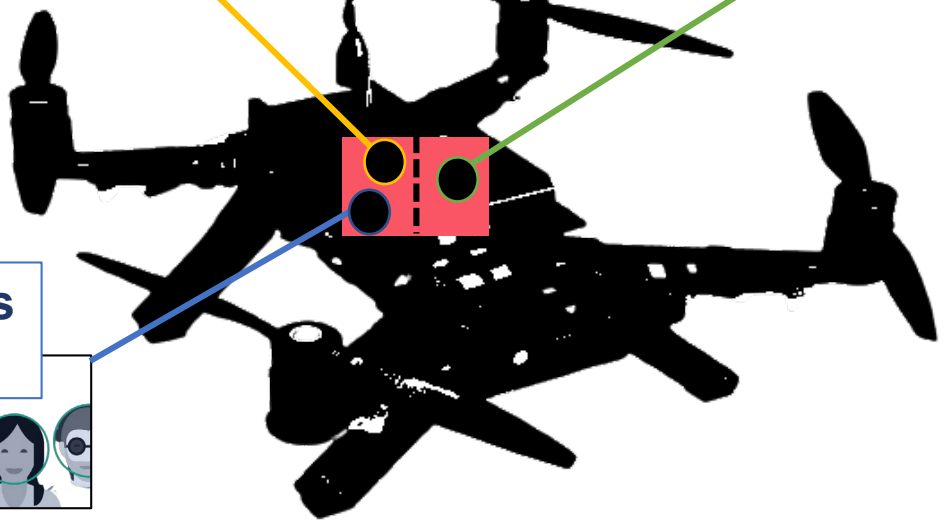
Separation-Kernel — **Partitioning Hypervisor**

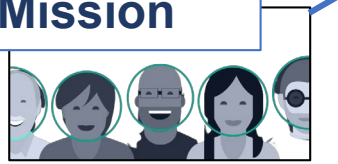


Backup CLEANFLIGHT

Flight Control CLEANFLIGHT



Autonomous Mission



Thank You

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Image courtesy: https://www.slideteam.net/flying-drone-robot-with-two-propellers.html