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Toward Next Generation Adaptive Cyber-Physical-Human Systems

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By
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Outline

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- Cyber-Physical-Human Systems
- Adaptive CPHS and Key Challenges
- Adaptive CPHS System Concept
- Adaptive Bi-Directional CPH Decision System
- Real-world Scenario
- Prototype Implementation
- Summary
- Way Ahead

Research Objectives

Investigate innovative approaches for developing next generation adaptive CPH decision systems in which human(s) and CP elements jointly perform tasks and adapt as needed while reducing human oversight and error

Team

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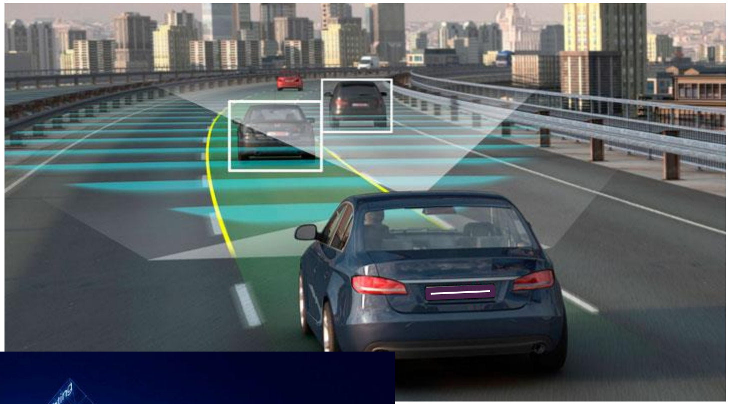
- Prof. Dan Erwin, Co-Investigator
- Dr. Ayesha Madni, Project Manager
- Edwin Ordoukhanian, Research Assistant
- Parisa Pouya, Research Assistant

Cyber-Physical-Human Systems

- A class of safety-critical socio-technical systems in which interactions between the *physical system* and *cyber elements* that control its operation are influenced by *human agent(s)*
- System objectives are achieved through interactions between:
  - **Physical system** (or process) to be controlled
  - **Cyber elements** (i.e., communication links and software)
  - **Human agents** who monitor and influence CPS operation
- **Distinguishing Feature:** Human (agents) intervene to redirect cyber-physical-system (CPS) or supply needed information, not just to assume full control or exercise manual over-ride

Exemplar CPHS

- Self-Driving Vehicles
- Smart Buildings
- Smart Manufacturing
- Medical Devices
- Unmanned Aerial Vehicles






Adaptive CPHS

- Respond to unexpected/novel situations during mission execution
  - adaptive response: re-allocate tasks, restructure, re-prioritize/ re-sequence tasks, shed/discontinue task
- Respond to new missions and objectives
  - through plan adjustment, plan adaptation, re-planning, new goal
- Incorporate humans in different roles
  - passive sensors (e.g., social networks)
  - active performers (e.g., intrusion detection, counter-insurgency)
- Learn from experience (observations, outcomes)
  - through machine learning (supervised, unsupervised, reinforcement)

Deficiencies in Existing Methods

- Address cyber, physical and human elements in isolation
- Lack semantics of time (no sooner than, no later than, etc.)
- Do not model interaction and synchronization constraints
- Are build-time approaches with no provision for learning during mission execution ("run-time")
- Do not attempt to minimize human oversight (slips) and errors (mistakes)

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Key Challenges in Adaptive CPHS

- Inferring human intent - from noisy EPS
- Incorporating strong time semantics - to ensure proper synchronization and sequencing of CPHS operation
- Ensuring shared context - during operation and adaptive mission execution
- Reducing human oversight and error in bi-directional CPH decision system

Adaptive Bi-Directional CPH Decision System Requirements

- Overarching requirement
  - eliminate/minimize human oversight and human error
- Specific requirements
  - ensure context is maintained during operation/adaptive execution
  - ensure human is not cognitively overloaded
  - ensure human is not asked to monitor infrequent events
  - ensure human and CPS are not assigned tasks they do poorly
  - ensure human and CPS are assigned tasks they do well
  - ensure neither is assigned tasks that each performs poorly

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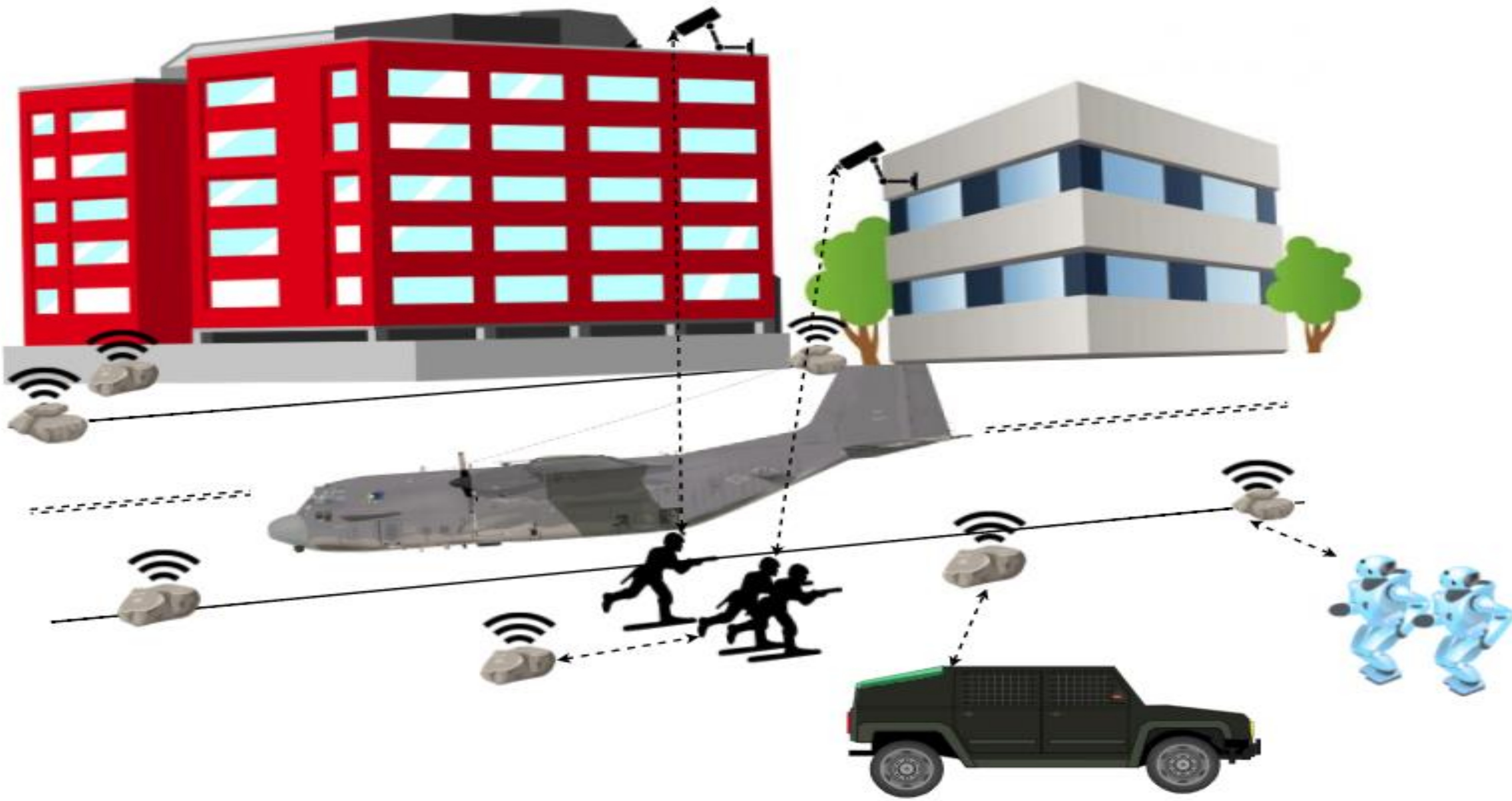
Adaptive Task Allocation in CPH Decision System

- Human and CPS have different strengths and limitations
  - for planning and decision-making tasks
- There are tasks that:
  - (1) both do poorly (e.g., rapid risk assessment)
  - (2) both do well (e.g., option selection)
  - (3) human does better than CPS (e.g., novel option generation)
  - (4) CPS does better than humans (e.g., recall of known options)
  - (5) better together than either alone (e.g., localization and identification)
- Implications:
  - task performance regimes include: both poor at; both good at; human poor at, CPS good at; CPS poor at, human good at; CPS superior to human; human superior to CPS
  - importance of context awareness and dynamic context management
  - avoid (1) and capitalize on (2) through proper design of CPHS
  - exploit flexibility afforded by (3) and (4) by allocating tasks on the basis of other criteria such as availability, cognitive load
  - recognize context where shared task performance (5) is called for
- Expected Outcome
  - reduced human oversight and human error

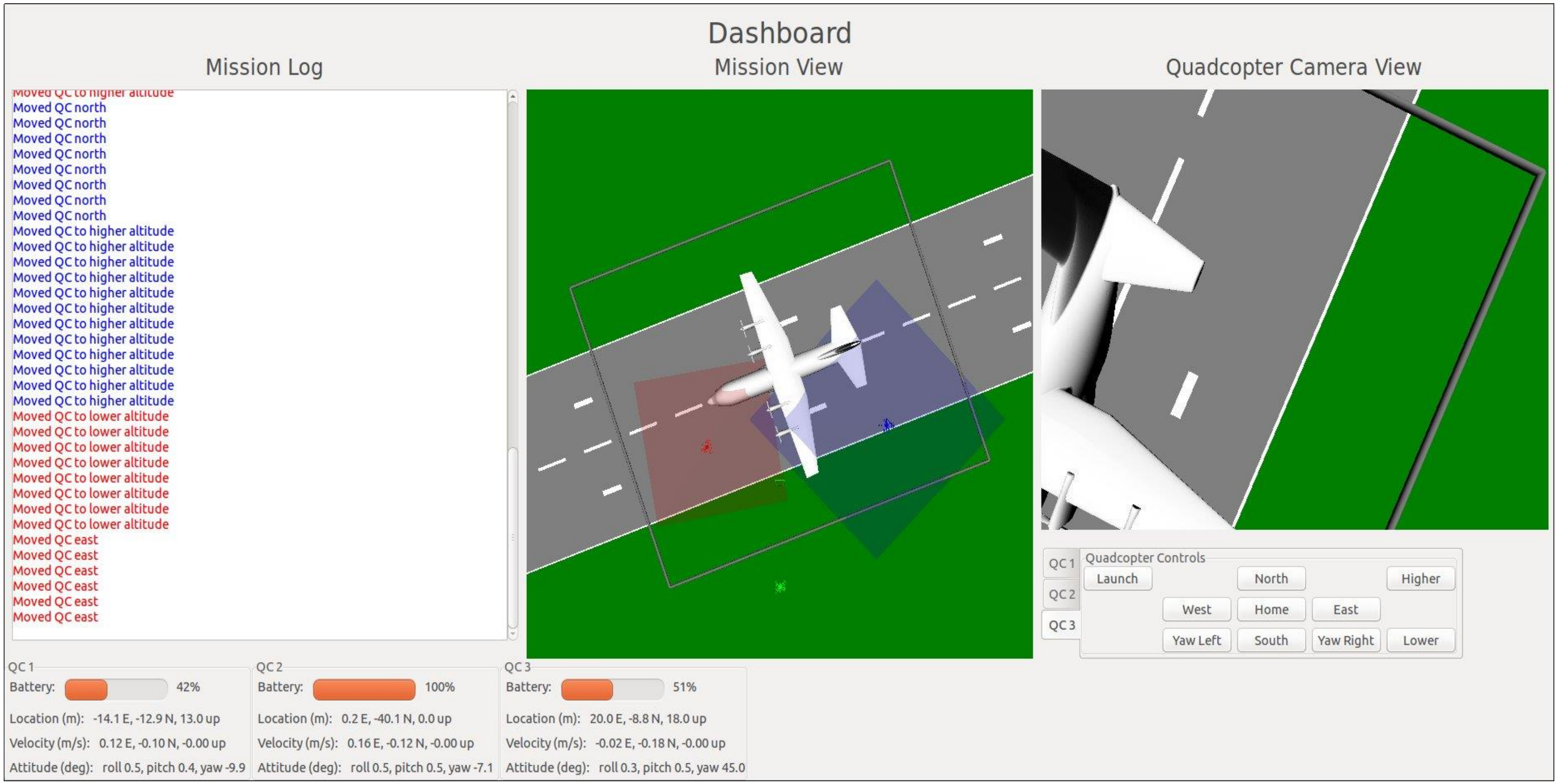
Illustrative Example:
Security of Parked C-130 Aircraft



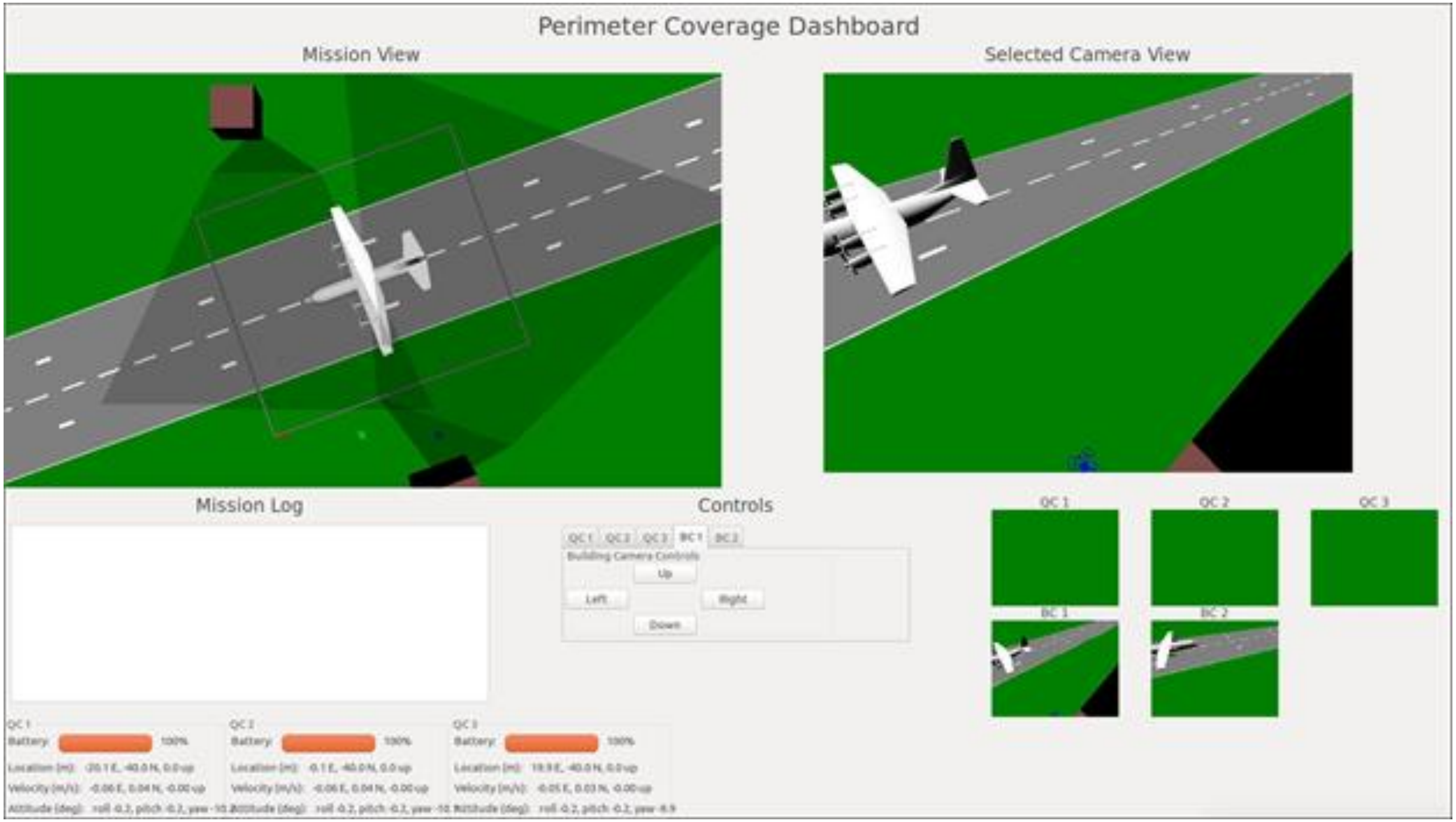
Landed Aircraft Security Scenario:
Task Reallocation to Maximize Perimeter Coverage

- **Scenario**
  - C-130 troop transport aircraft has landed on an airstrip
  - maintain close surveillance of aircraft perimeter
- **Collection Assets**
  - building-mounted fixed video cameras, LWIRs, unattended ground sensors
  - quadcopter drones with downward facing cameras
- **Goal**
  - maintain video coverage of aircraft perimeter despite disruptions
  - e.g., loss of drone, loss of building camera
- **Actions Available (simple/compound)**
  - reposition current flying drone; launch reserve drone
- **System States**
  - Green (full perimeter coverage); Yellow (responding to disruption);
    Red (lack capability to restore coverage); in red state, CPS alerts commander

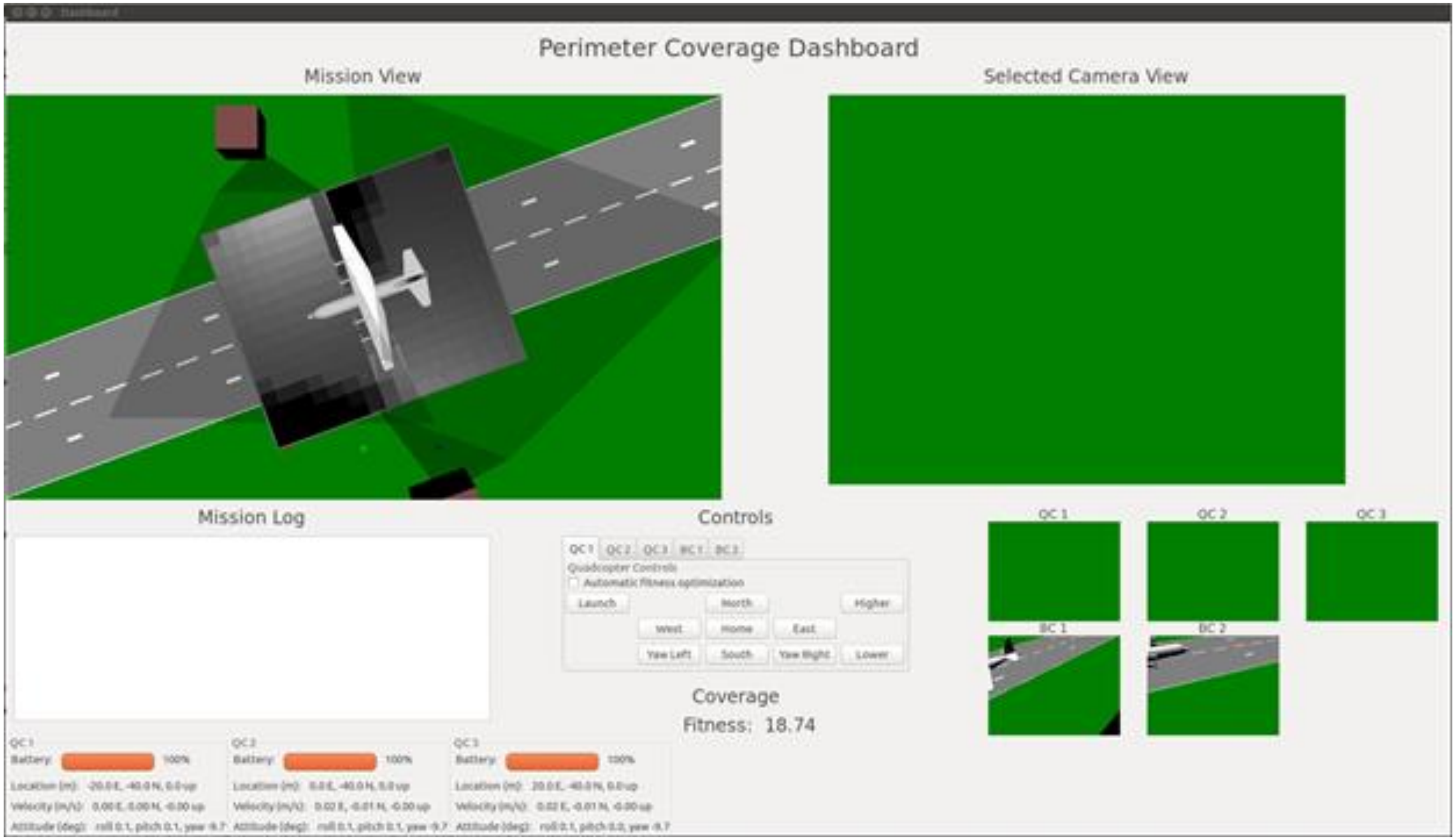
Management Dashboard: Task Reallocation Interface



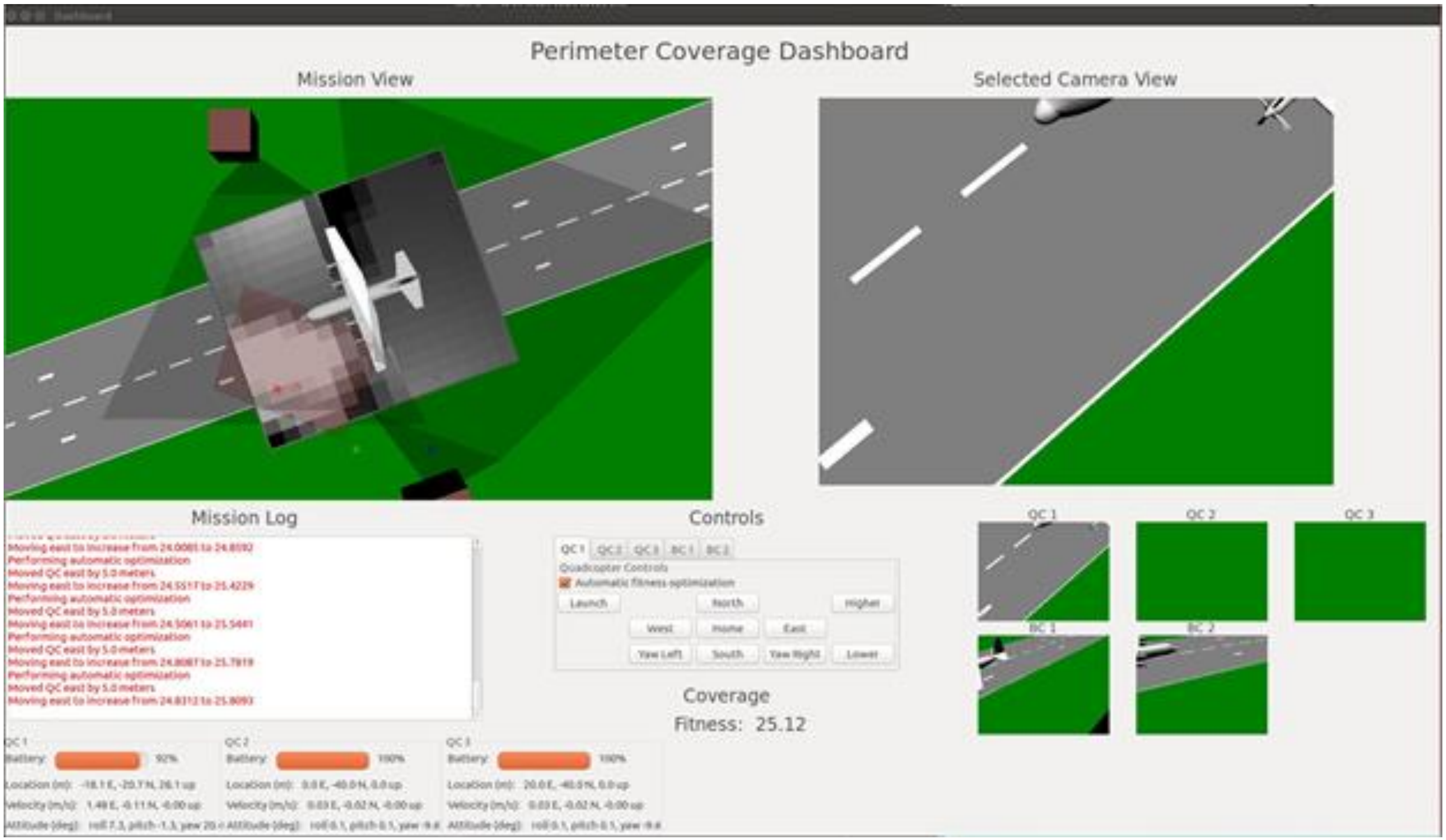
Scenario Simulator



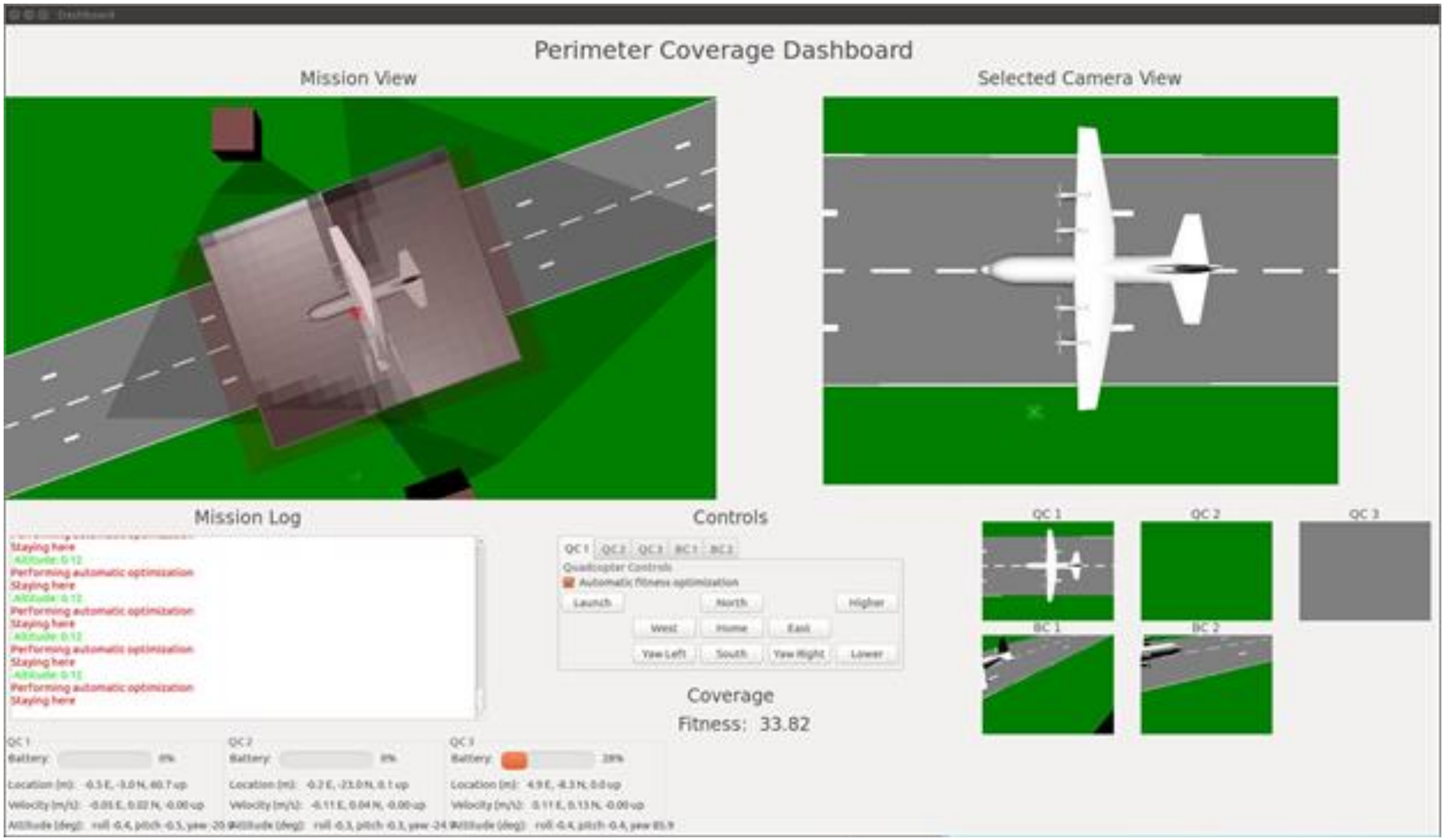
Dashboard Showing Coverage



Dashboard Showing One Quadcopter During Optimization of Fitness Function



Dashboard Showing Optimal Location for a Single Quadcopter



Dashboard Showing Optimal Locations for Three Quadcopters

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Summary

- Next Generation Adaptive CPHS
  - safety-critical systems - range from small device to large-scale SoS
  - humans potentially play multiple roles - leads to increased complexity
  - need to operate safely in uncertain, potentially deceptive environments
- Existing system design tools are inadequate for adaptive CPHS
  - address cyber, physical, and human elements in isolation - do not address interactions between cyber, physical and human elements
  - lack means to represent timing and synchronization constraints
- Technical challenges
  - infer human intent from electro-physiological sensors
  - incorporate strong time semantics
  - maintain shared context
  - reduce human oversight and human error
- Approach
  - principles of human-CPS decision systems based on psychological principles
  - flexible knowledge representation with temporal semantics
  - introduce Digital Twin in virtual environment for performance improvement and predictive maintenance
  - machine learning (supervised, unsupervised, reinforcement)

"The hope is that, in not too many years, human brains and computing machines will be **coupled** together very tightly, and that the resulting **partnership** will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today."

–J. C. R. Licklider *"Man-Computer Symbiosis" IRE Trans. on Human Factors in Electronics, vol. HFE-1, pp. 4-11, Mar. 1960*

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SERC Principal Investigator

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- **Research Sponsors:** DoD-SERC, AFRL, AFOSR, ARI, ARL, RDECOM, ERDC, TATRC, DARPA, OSD, NASA, DOE, NIST, ONR, NAVAIR, NAVSEA, SPAWAR, MARCOR, DTRA, MDA, , GM, Boeing, NGC, Raytheon, Orincon, SAIC,
- **Recent Awards**
  - 2018 INCOSE Outstanding Service Award
  - 2018 IEEE SMC Systems Science and Engineering Award for MBSE TC (most influential)
  - 2017 Dean's Award for Innovation in Teaching and Education
  - 2017 John F. Guarrera Engineering Educator of the Year from Engineer's Council
  - 2017 James E. Ballinger Engineer of the Year Award from OCEC
  - 2016 Boeing Lifetime Achievement Award (Contributions to Boeing, Aerospace and Nation)
  - 2016 Boeing Visionary Systems Engineering Leadership Award
  - 2014 INCOSE Lifetime Achievement Award
  - 2013 IIE Innovation in Curriculum Award
  - 2011 INCOSE Pioneer Award
- **Recent Authored Books**
  - Transdisciplinary Systems Engineering: Exploiting Convergence in a Hyper-Connected World (foreword by Norm Augustine) Springer, 2018
  - Tradeoff Decisions in System Design (foreword by John Slaughter), Springer, 2016

Thank You

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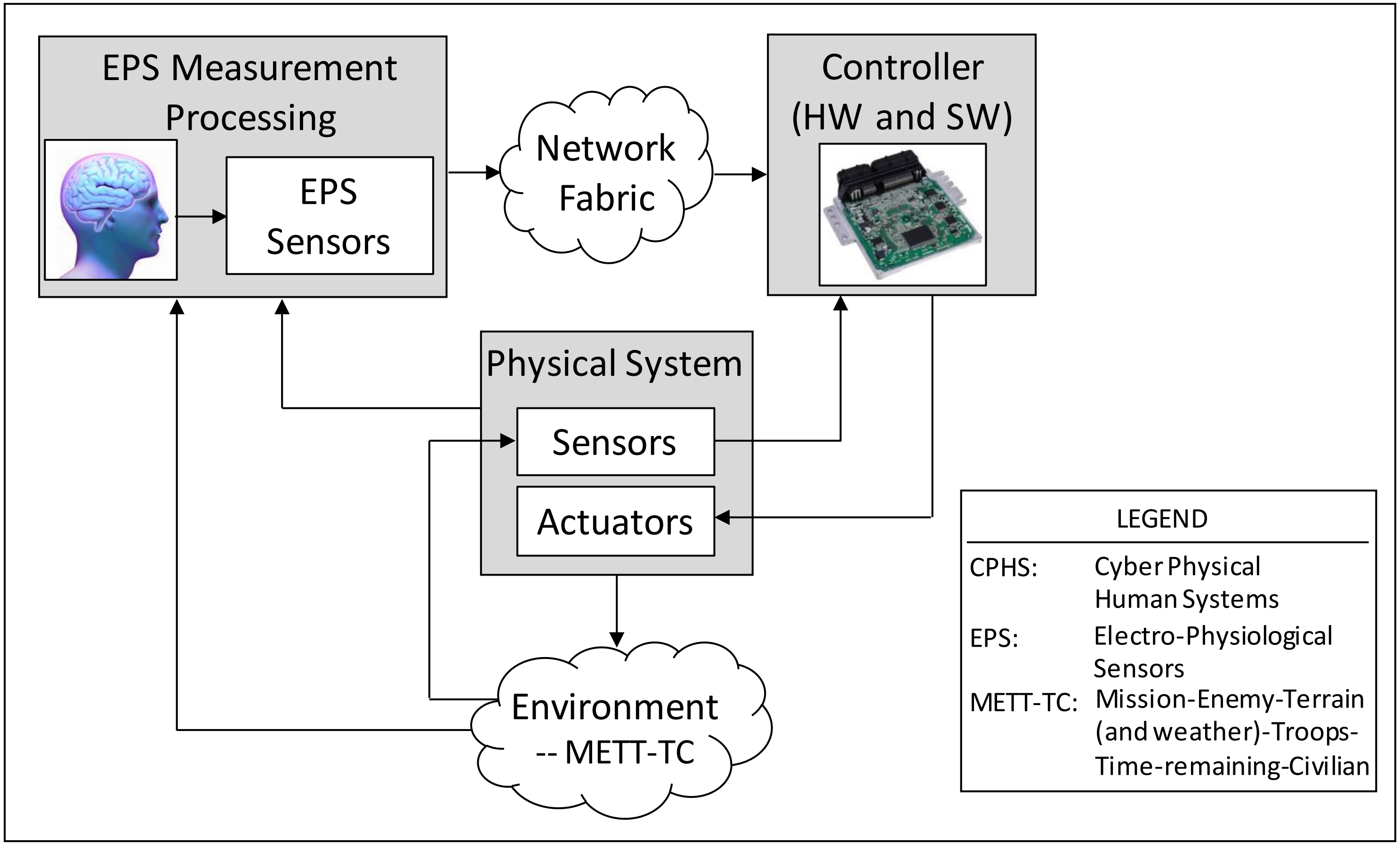
Adaptive CPHS: System Concept



UI for Area Monitoring and Decision Making