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Enhanced AI Decision Process for A-eVTOL System

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Outline

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3. Challenges to the Dynamic Subsystems Management Framework (DSMF)
4. Effects of Senor Reliability
5. MTBF Effects on Q Learning Process
6. AI System Decision Making Through Q-Learning
7. Q Learning Case Study of Obstacle Avoidance
8. Summary

1. Background

Global X - Global Crossing Airline Group [1]

- eVTOL is part of the INVOVATE 28 plan by the FAA
- Autonomous- electric Vertical Takeoff and Landing (A-eVTOL) System is the next generation of eVTOL
- A-eVTOL system requires AI to make decisions based on sensor data to maintain the normal operational flight profile
- When sensors deviate from regular operation, AI cannot make proper decisions based on defective and missing data.

Benefits of A-eVTOL

	eVTOL	A-eVTOL (Second Generation)
Weight	One pilot: 150 lbs. Two pilots: 300 lbs.	No pilot : Up to 300 lbs saving reduce battery consumption or increase transport distance
Pilot training	Train a minimum of 100,000 pilots for worldwide operation[2]	No pilots only AI computers
Labor cost	Pilot cost is part of the ticket price	AI computers are less costly
Hours of operation	Labor laws limited the number of hours pilots can fly per day	No restrictions on operation.

2. System Approach

- Flight control decision dependent on multiple other validated sub-systems
- The dynamic subsystems management framework (DSMF) is a set of integrated capabilities to guide the AI decision-making process
    - ➢ Regulate bad sensors, communication systems, and flight path maneuvers to minimize the AI decision error from deviating from regular operation
    - ➢ Leverage sensor reliability data to contribute to the decision process
    - ➢ Q learning process is chosen for this AI application

Pros and Cons of Q- learning

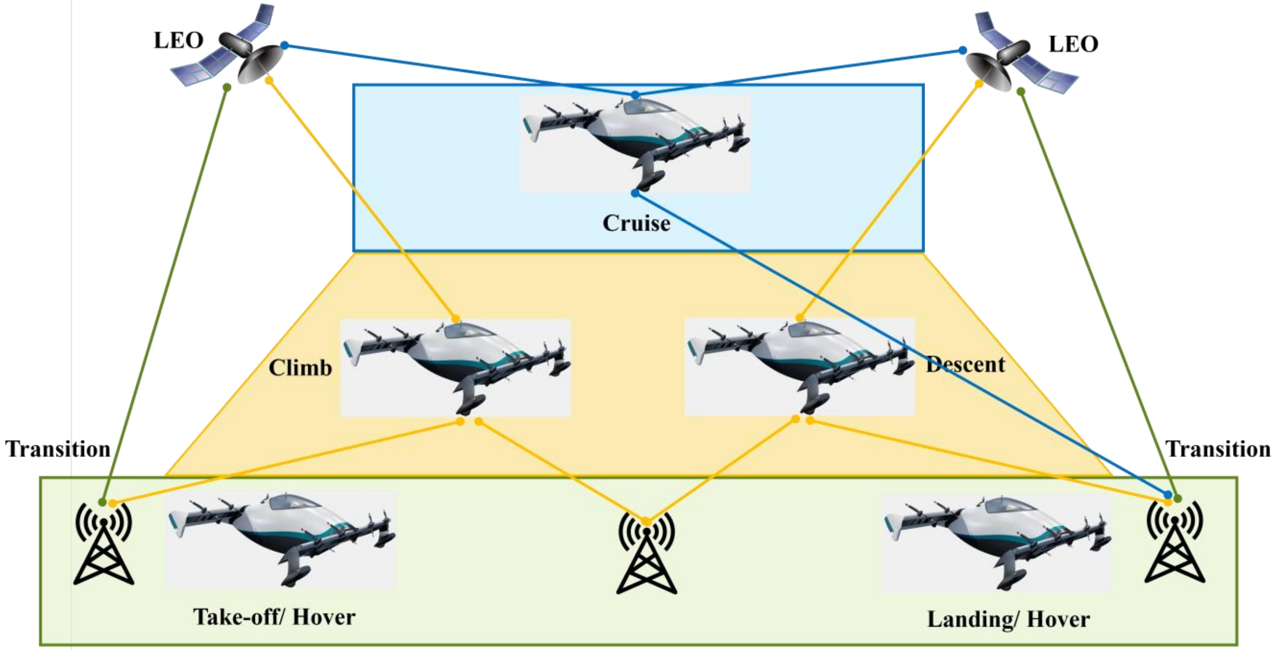
Advantages of Q-learning

• Trial and Error Learning: Continues to improve based on past mistakes
• Better Decision-Making: Memory of successful actions to minimize bad choices
•Autonomous Learning: Process through exploring with no supervision

Disadvantages of Q-learning

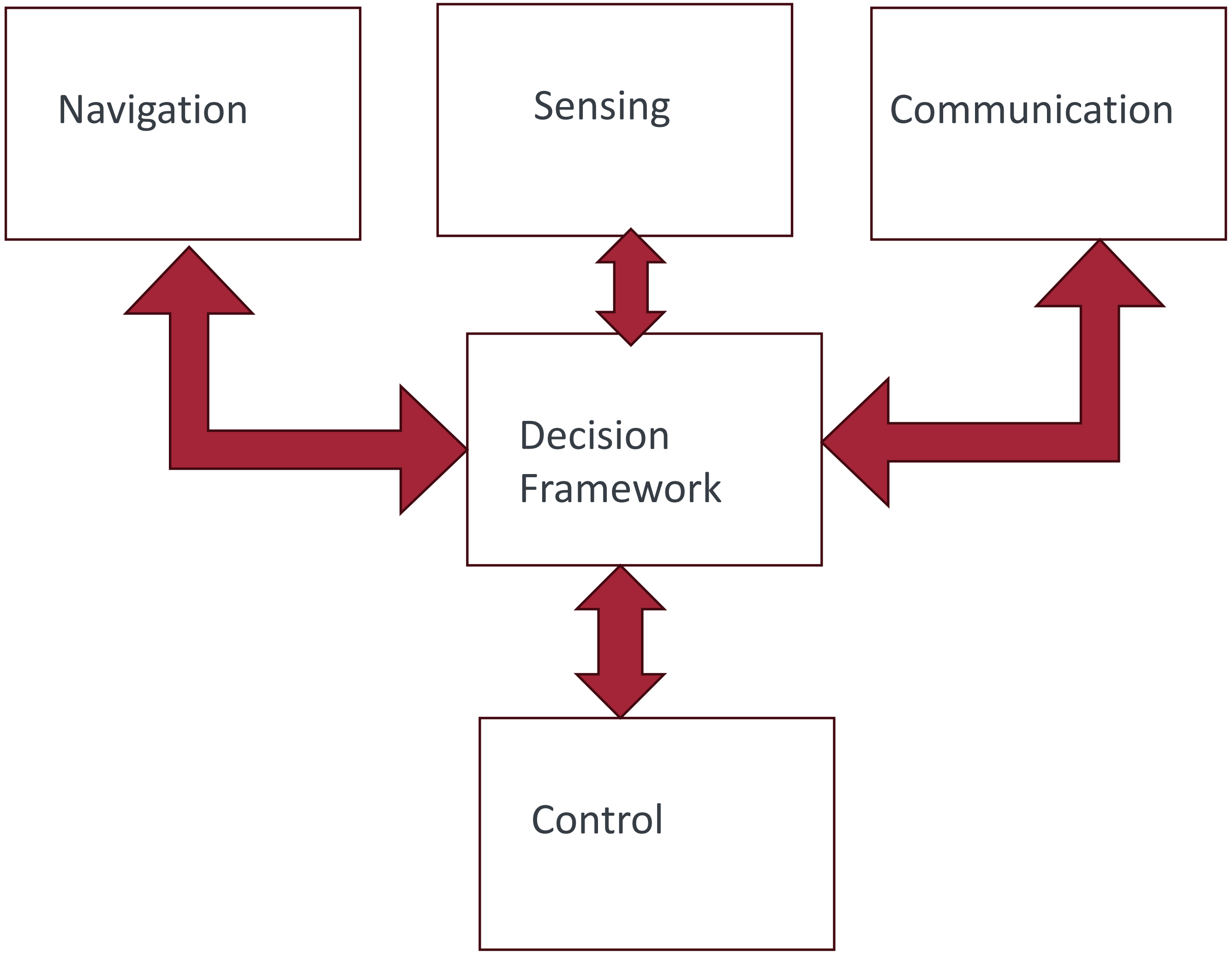
• Slow Learning: Many iterations with the possibility of a longer time for complicated tasks
• Large dimensionality: Squares of number states and actions can grow rapidly
• Limited to Discrete Actions: Need to add a feedback loop to mimic continuous actions for the real world

Maintain the A-eVTOL Flight Profile



- Making flight decisions with AI
  - ➢ Test case of obstacle avoidance
- Sensor's prioritization
  - ➢ Which sensors contribute more to the current situation
- Data Management
  - ➢ Continuously updates information to improve the obstacle avoidance process

AI System Decision Process for A-EVTOL



Navigation
- Maintain flight path with adjustment
- Develop an avoidance strategy

Sensing
- Sensing flight environment
- Adjust sensors in real-time

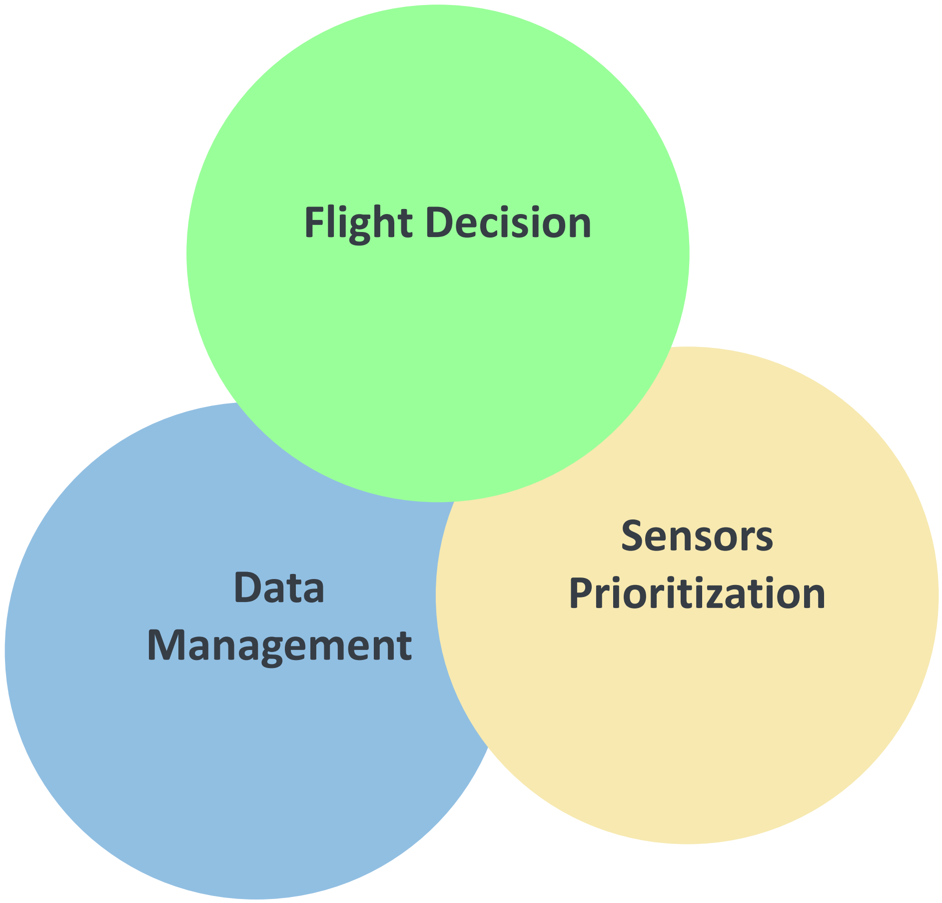
Communication
- Network connectivity
- Coverage and data throughput
- Information sharing and security

Decision Framework
- Dynamic Sensor Management Process
- Communication Management Process
- Control Management Process

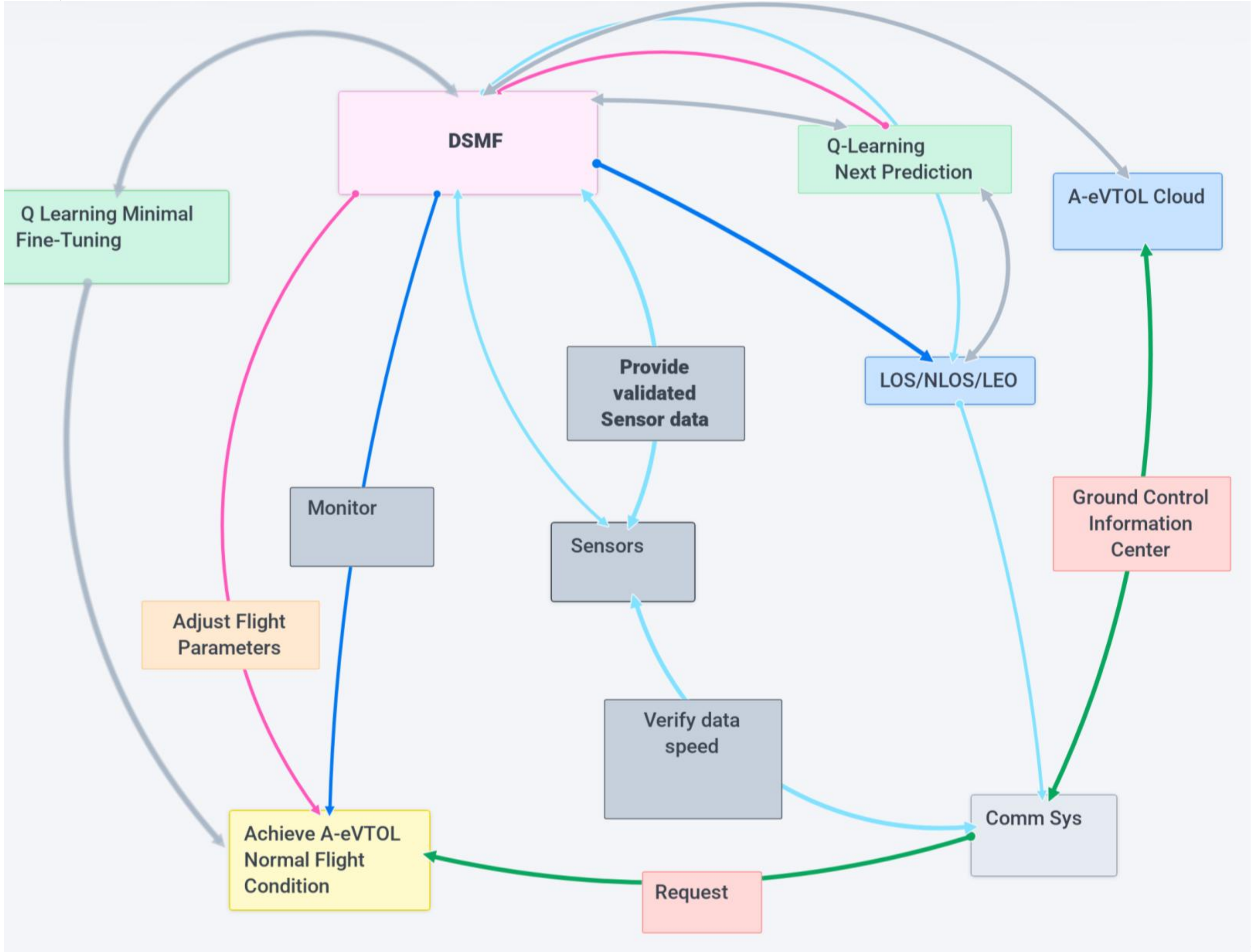
Control
- Flight path planning
- Situation adjustment of flight path
- Normal flight control of takeoff, cruising, and landing

3. Challenges to the Dynamic Subsystems Management Framework (DSMF)

- Simultaneous tasks resolution
- Real-time outputs to current obstacle avoidance
- Data Management
  - ➢ Ground, air, and space data
  - ➢ Sorting out the most helpful information



Systemigram Approach of DSMF

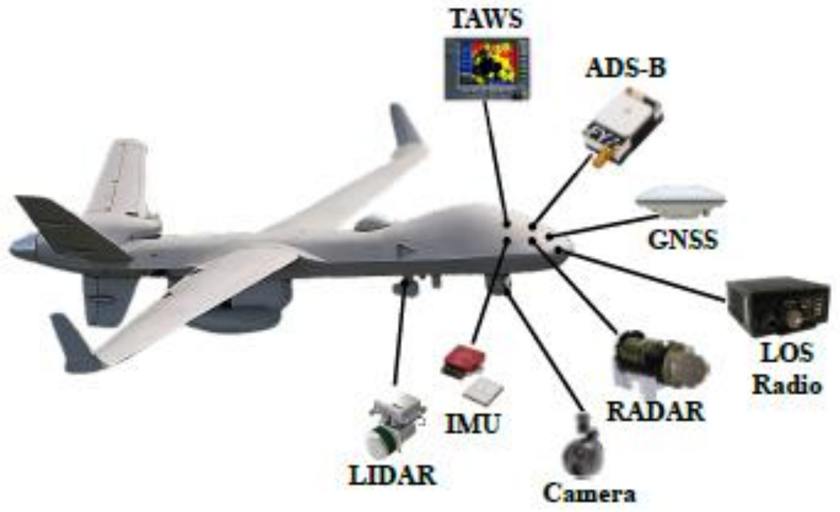


Systemigram

- System diagram to show interactions of the Dynamic Subsystems Management Framework (DSMF)

- Show interactions between DSMF and other subsystems
  - ➢ Sensors
  - ➢ Comm,
  - ➢ Q Learning AI
  - ➢ A-eVTOL Cloud

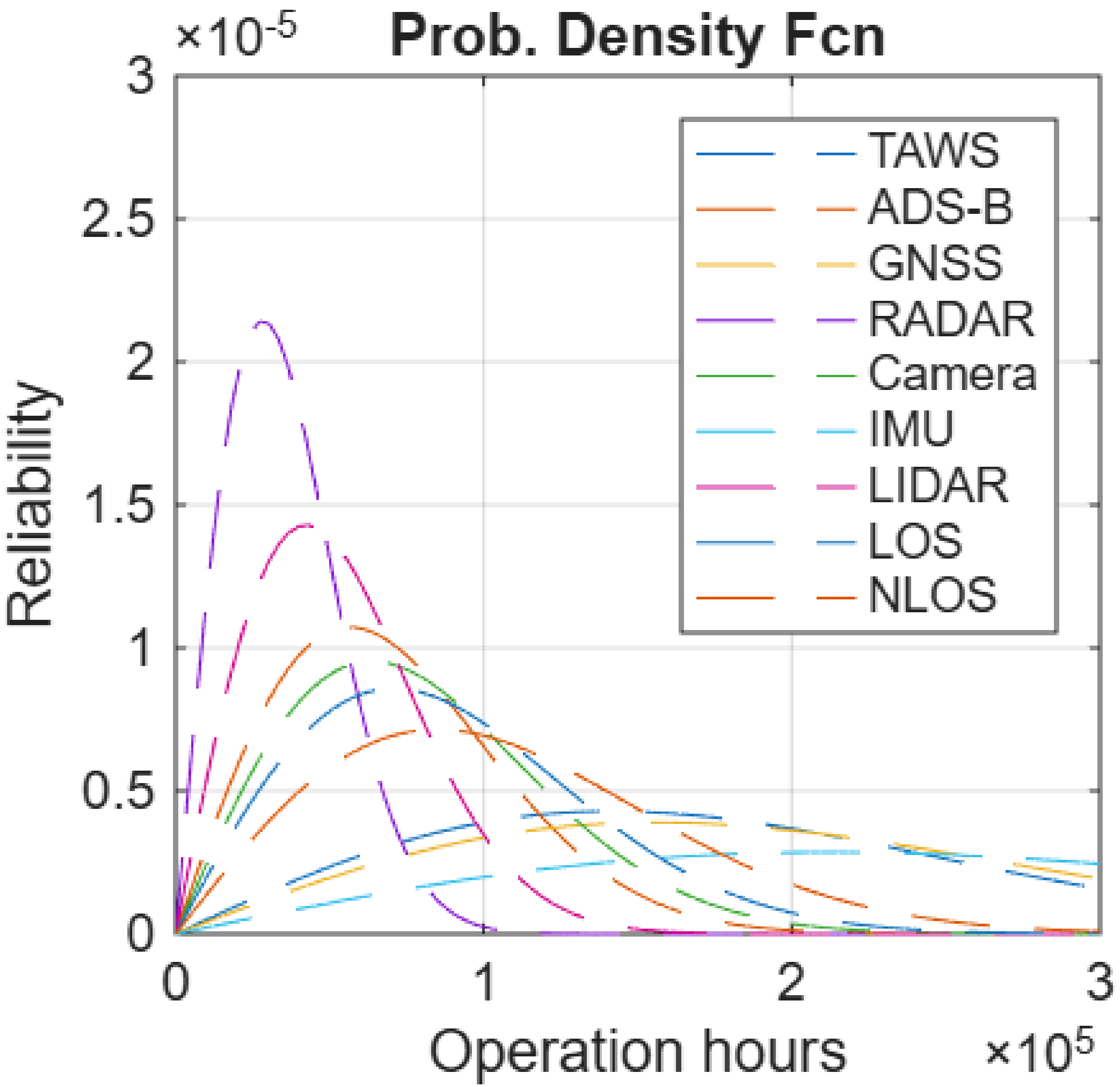
4. Effects of Sensor Relaibility



Global Hawk sensors from various open sources

- Heterogeneous sensors have different failure rates
  - Influence maintenance concept
  - Affects operation hours
- Develop a reliability baseline for acceptable risk
  - Influence the type of design
  - Affect the number of flights per day
- Leverage the reliability for flight certification
  - FAA rules on critical system reliability

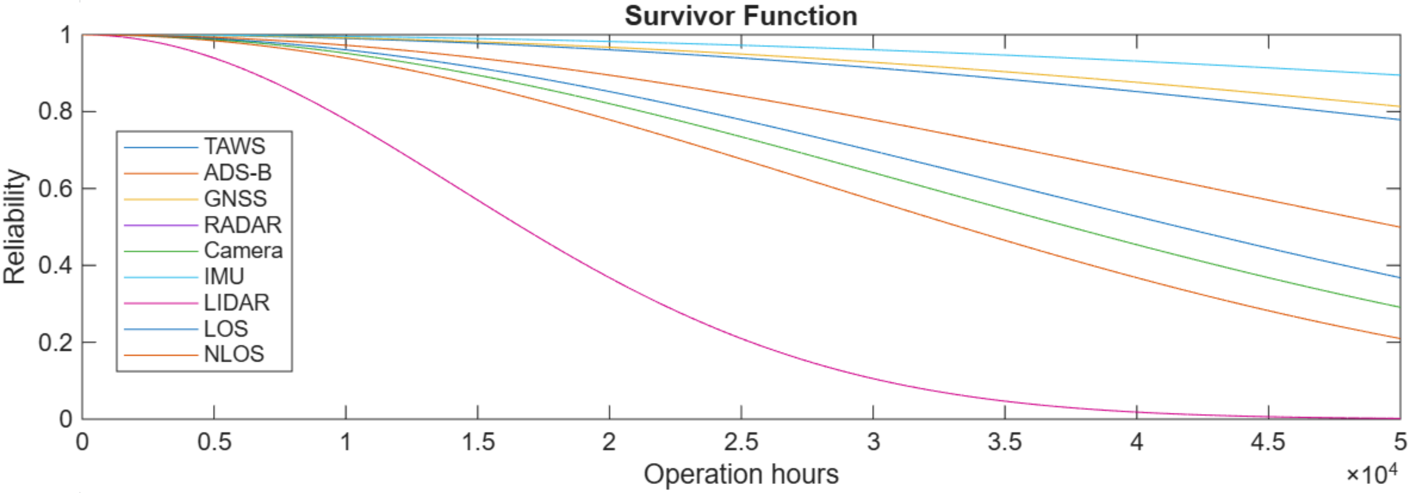
Reliabilty of Sensors



Sensors in UAV applicable for A-eVTOL

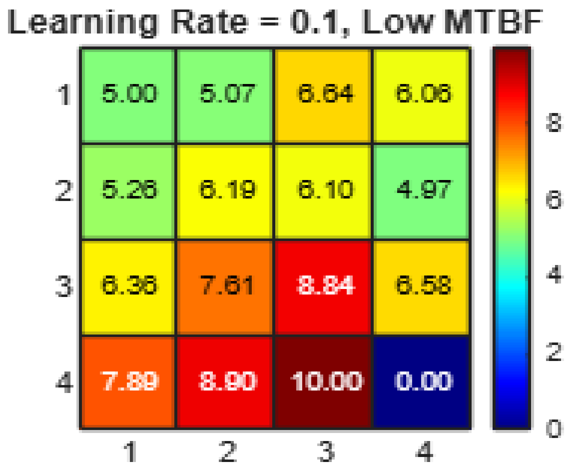
TAWS: Terrain Avoidance Sensor
ADS-B: Automatic Dependent Surveillance-Broadcast
GNSS: Global Navigation Satellite System
Radar: Long-range sensor
Camera: Day/night
IMU: Inertial Measurement Unit
LIDAR: (Light Detection And Ranging)
LOS: Line-Of-Sight communication system
NLOS: Non-Line of Sight communication system

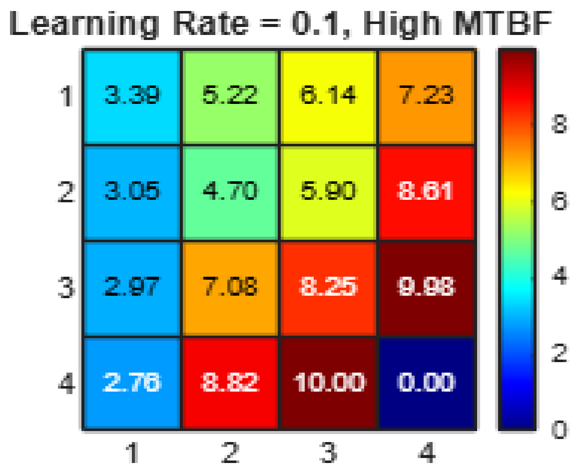
Setting the Redundancy Probability



- Use the survival function to confirm operation beyond the Mean Time Between Failure (MTBF)
- Optimize risk for the operation
- Too high a value will increase the system cost
- Too Low will increase maintenance costs

5. MTBF Effects on Q Learning Process





- Agent fails-Receives a large negative reward
- The MTBF variable- Indicate the frequency of these failures.
- A lower MTBF means the system is less reliable compared to other systems
- System is very reliable (high MTBF, low failure rate)
  - ➢ Learned maximum Q-values for each state
  - ➢ Color intensity will show which states have high expected long-term rewards.

6. AI System for A-eVTOL Control Decision Making

An A-eVTOL System requires making flight control decisions in real-time without pilots. The Artificial Intelligence (AI) system's decision parameters are adaptable to different phases of the flight operation.

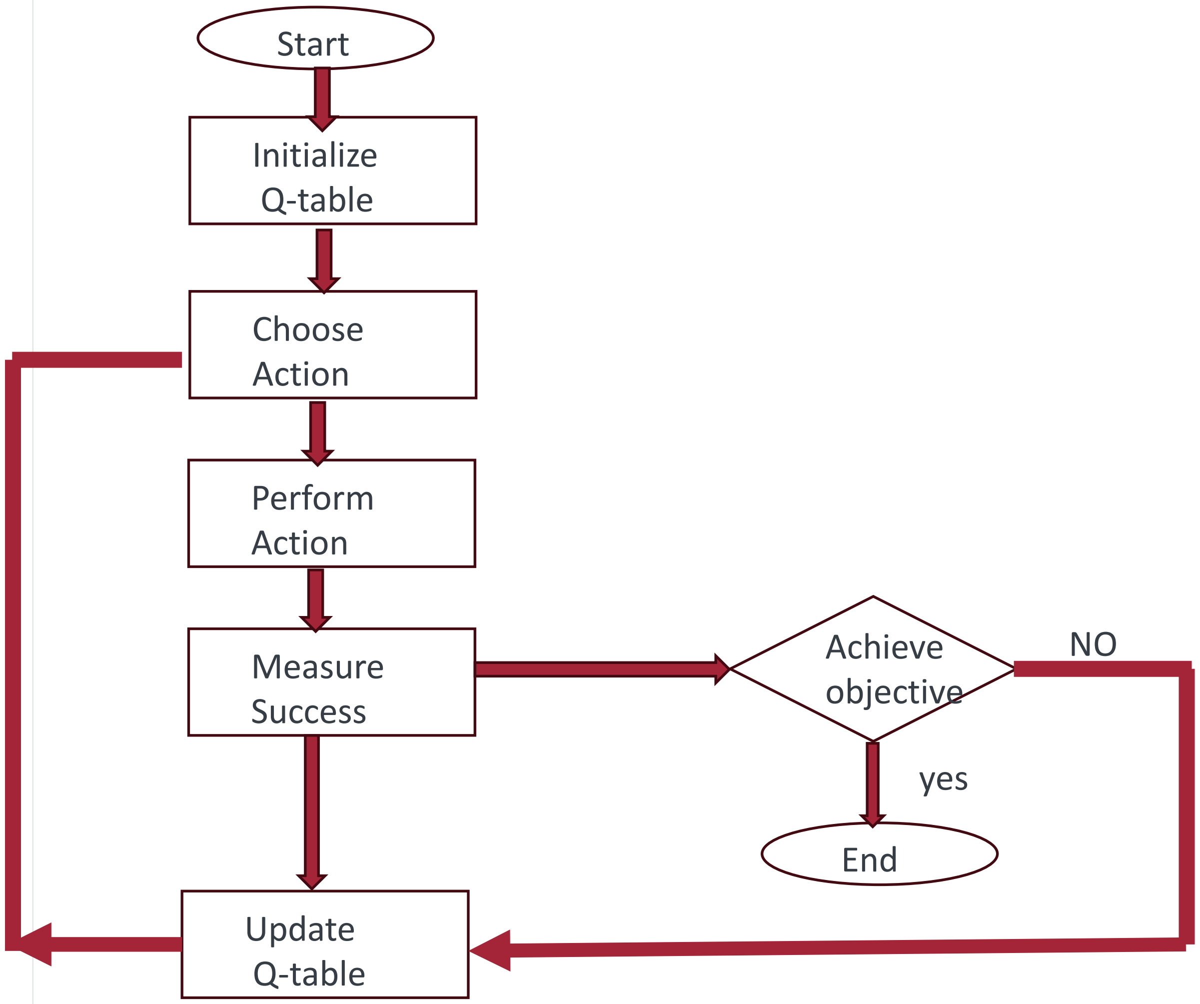
Objectives

- Flight adjustment and correction for all three phases of the flight profile
- Optimize sensor information
- Updates and optimizes communication links.
- AI decision-making is safe enough for A-eVTOL operation certification

Deep Reinforcement Learning Applicability for A-eVTOL

- Agent learns through trial and error within each environment.
  - Three critical tasks: takeoff, cruise, and landing
- DRL agents learn by exploring their surroundings
  - Navigation, Communication, and Control mechanism
- Taking actions and receiving feedback in the form of rewards or penalties.
  - Sensor inputs information
  - Feedback on successful action or not
- This continuous cycle of interaction is designed to maximize its cumulative reward.
  - Improve decision cycle time
  - Fine-tune accuracy

Q-Learning Algorithm Process



- 1. Initialization: Agents for navigation, communication, and control
- 2. Interaction: The agent interacts with its surroundings
- 3. Learning: Agent keeps track of its experiences
  4. Exploitation: The agent strikes a balance between utilizing well-known actions and experimenting with new ones.
- 5. Reward Maximization: The agent learns to select activities that will yield the greatest possible total rewards.
- 6. Convergence: The agent's policy improves and remains stable over time.

Bellman's Equation

- Formula used to calculate the value of a current state and determine the optimal action

$Q(s,a)=R(s,a)+\gamma maxaQ(s',a)Q(s,a)$ [3]

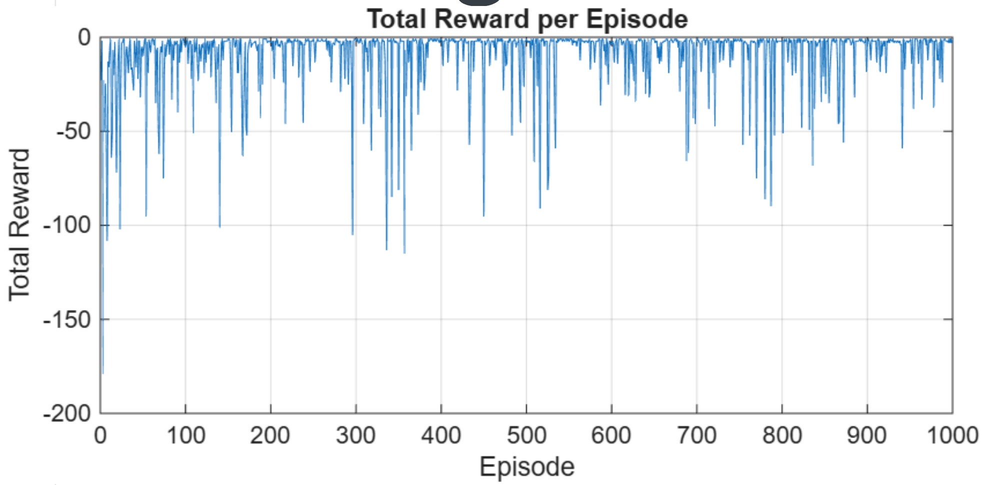
- Q(s, a) is the Q-value for a given state and action pair
- R(s, a) is the immediate reward for taking action a in state s
- γ (gamma) is the discount factor
  - ➢ Indicate the importance of future rewards.
- maxQ(s′,a)
  - ➢ maximum Q-value for the next state s' and all possible actions.

7. Q Learning Case Study of Obstacle Avoidance

Definition

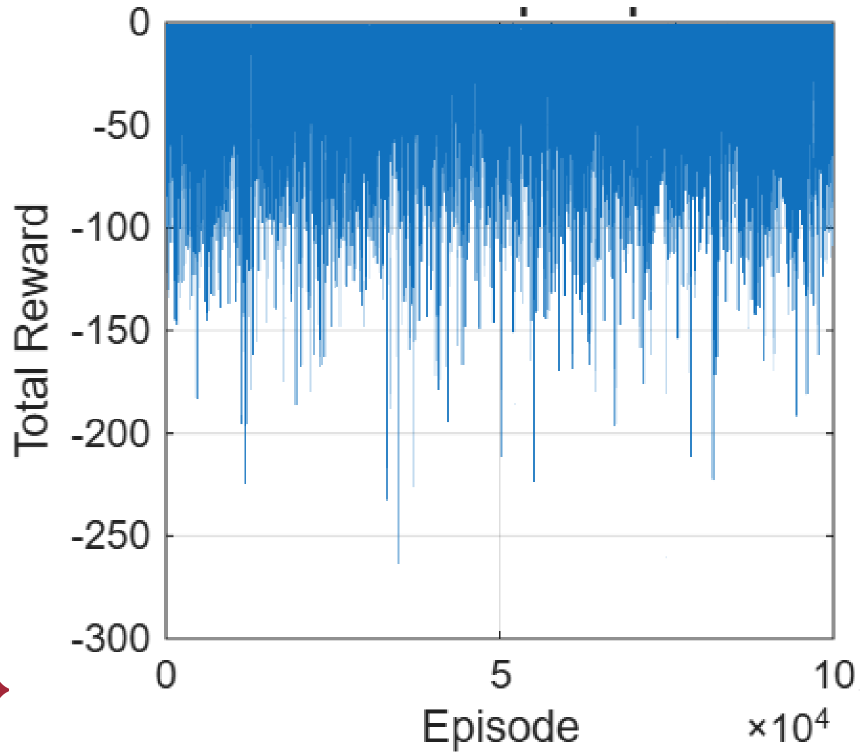
- Static target: A-eVTOL speed is much greater than the Obstacle (birds, balloon, buildings, etc.)
- Dynamic targets: The speed is comparable to the A-eVTOL speed
    - ➢ Another A-eVTOL, helicopter, UAV
- States 4 X 4
- Actions: 5
    - Move up
    - Move down
    - Move left
    - Move right
    - Hovering (Not moving)

Q Learning results of Obstacle Avoidance



1K Episodes

- Total reward vs Episodes
- Avoid getting stuck at the grid walls or the borders
    - ➢ value less than 100
- More episodes create more chances to go into the walls



100K Episodes

8. Summary

Why DSMF is so crucial to the AI Decision Process for A-eVTOL System

1. Integrated process: Work with communication, navigation, and control functions to achieve proper decisions

2. Leverage the reliability data

3. Construct a model to verify the simulated data performance

4. Q learning leads to an optimal solution

Future Work

1. Max episodes within the FAA require a real-time response
2. Different Q Learning algorithms and their effect
3. Optimized the Q Learning with the shortest path
4. Moving obstacles

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THANK **YOU**

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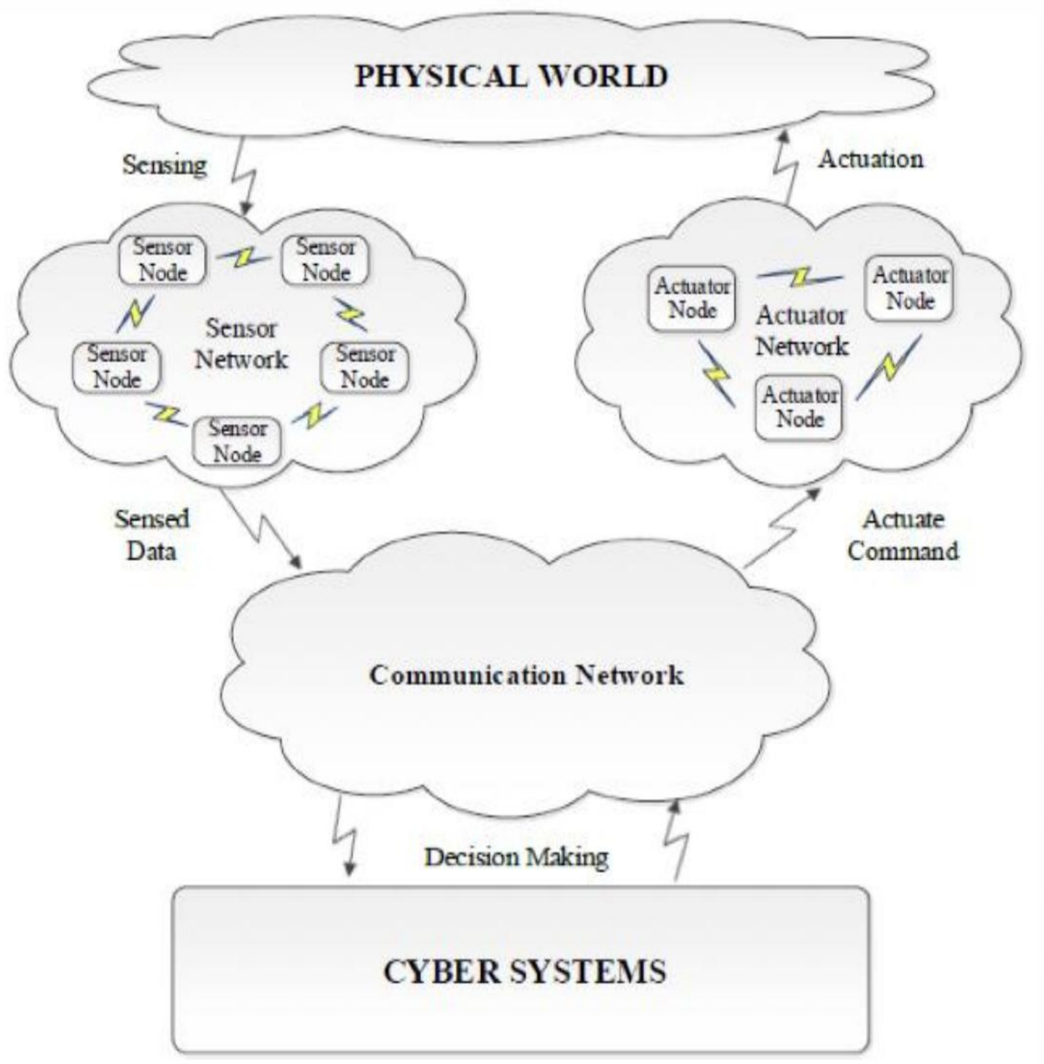
Backup slides

Cyber Physical System Holistic View



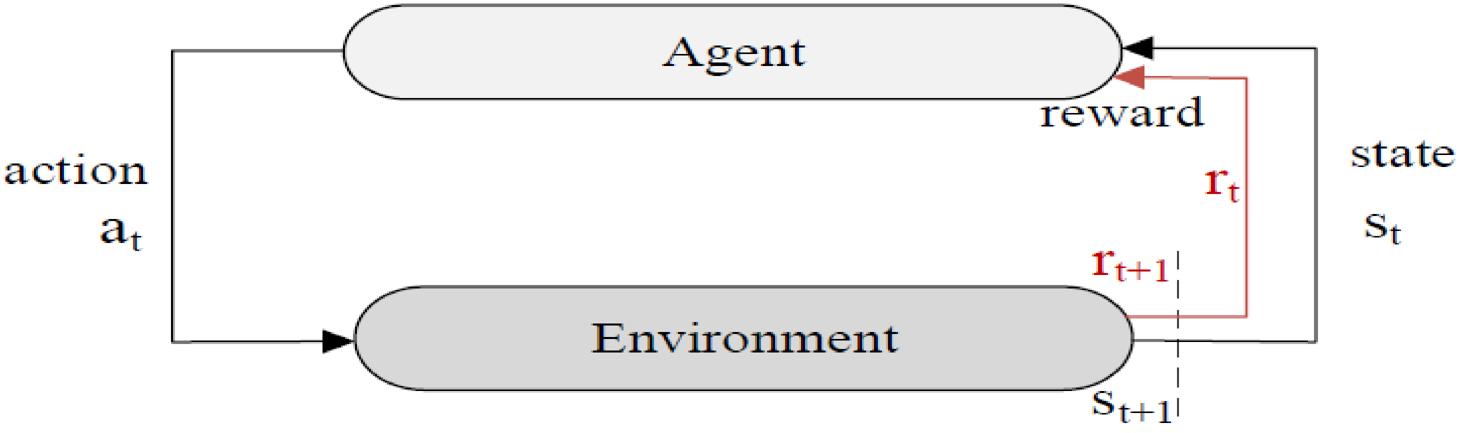
[4]

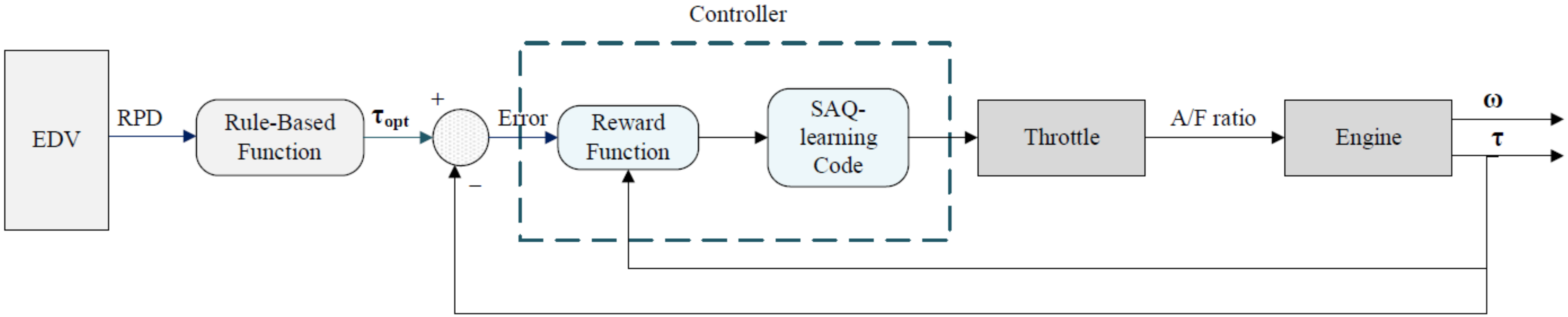
MTBF of Various Sensors

Subsystem	Criticality	MTBF (hrs)	Phase	Redundancy / Comm Profile
LOS Radio	High	50,000	Takeoff, Landing	Dedicated LOS; URLLC
LIDAR	High	20,000	All	Sensor fusion with Radar backup
Camera	Medium	40,000	Cruise	Compressed; eMBB class
GNSS	Low	110,000	All	Cold fallback; delay-tolerant
IMU	Very High	150,000	All	Hot spare; URLLC
NLOS Radio	Medium	60,000	Urban Cruise	Opportunistic fallback path

TAWS = 100K; ADS-B: 40K; RADAR: 20K;

Improve Q- learning for Real time A-eVTOL Application





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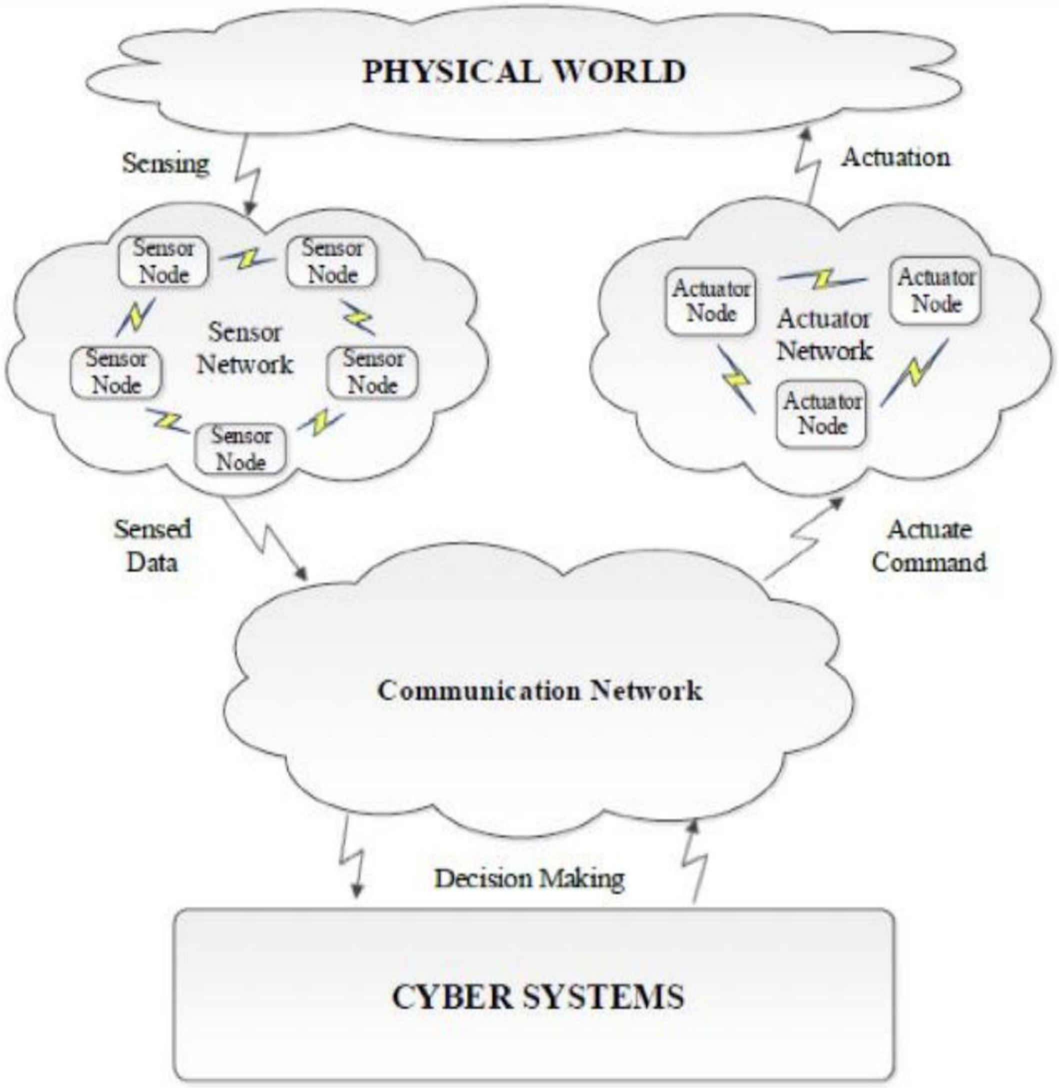
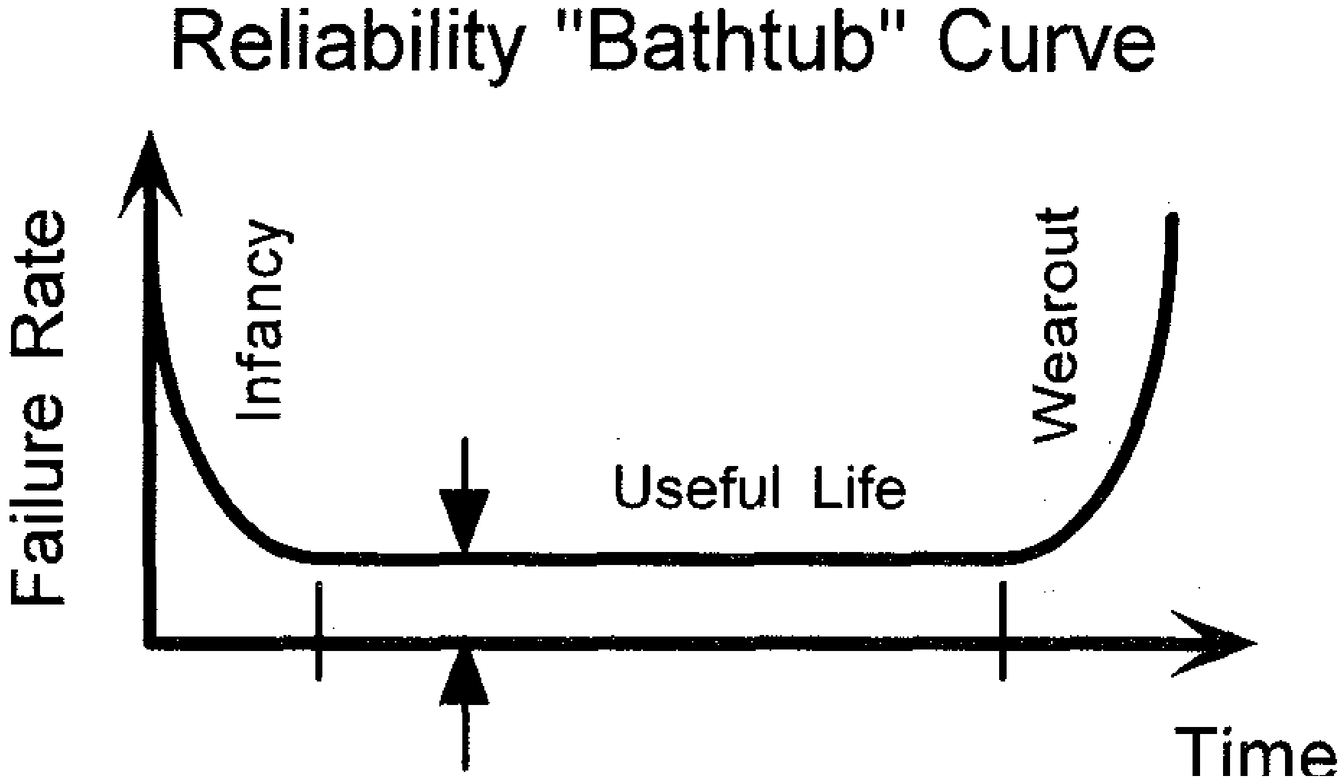
Cyber Physical System Holistic View



Mahnamfar, Amin, and Nafiz Ünlü. "Cyber-physical systems and their security issues." Savunma Bilimleri Dergisi 1.41 (2022): 97-118.

Literature Review: Principles of fault tolerance



$$Unavailability = 1 - Availability = \frac{MTTR}{MTTF + MTTR}$$

- Mean Time Between Failure (MTBF), although for components that will be taken out of service and not repaired, the more exact term is Mean Time To Failure (MTTF)

- Mean Time To Repair (MTTR)