High Density Vertiplex: Scalable Autonomous Operations Prototype Assessment Simulation

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SciTech, January 08-12, 2024

Introduction

- Urban Air Mobility (UAM) proposes an innovative way to transform transportation in urban environments
- Advancements in technology allow for solutions that were not possible prior
- However, these solutions require more research and development through simulation and flight testing
- NASA's High Density Vertiplex (HDV) Sub-project is dedicated to researching and developing critical roles and infrastructure for high volume UAM operations
- A major component of the research is simulation of the roles and systems within a prototype UAM ecosystem

Background

- HDV created its own prototype of a UAM ecosystem for evaluating high density operations at vertiports
- The ecosystem included vertiport infrastructure, a vertiport automation system, and multiple roles: a Fleet Manager, a Vertiport Manager, and Ground Control Station Operators
- Evaluation included both simulated operations and flight operations with human factors data collection
- Simulation involved three groups of participants exercising five UAM scenarios
  - Each group included three Ground Control Stations Operators, one Fleet Manager, and one Vertiport Manager

Simulation Setup - Roles

- Ground Control Station Operator (GCSO)
  - Assigned one vehicle
  - Responsible for execution of an operation
  - Monitor's vehicle status while in flight
- Vertiport Manager (VM)
  - Responsible for monitoring status of individual vertipads at the vertiport
  - Closed vertipads as they become occupied, require maintenance, etc.
  - Use the Vertiport Automation System to help manage departure and arrival approvals to vertiport
- Fleet Manager (FM)
  - Responsible for operation submission to the ecosystem
  - Engaged the trial planner to replan operations as flight plan conflicts occur
  - Issued commands to ground control station operators to resolve flight plan conflicts

Simulation Setup - Facilities

- Remote Operations for Autonomous Missions (ROAM)
  - Location of the GCSOs and VM
  - Served as the remote operations facility
  - Supported human factors research on GCSO and VM
- Systems Integration and Validation Lab (SIVL)
  - Contained the hardware and software supporting the UAS simulator
  - Provided a simulated HHITL vehicle for each GCSO
  - Location the server running the Vertiport Automation System
- Airspace Operations Lab (AOL)
  - Location of the FM
  - Supported human factors research on the FM
  - Provided simulation traffic to scenarios through MACS traffic
- Autonomous Vehicle Applications Lab (AVAL)
  - Used for monitoring VM and FM software throughout operations

Simulation Setup - Components

- Human Hardware in the Loop (HHITL)
  - Quadcopter model with six degrees of freedom
  - Contained NASA Software, ICAROUS and Safe2Ditch, for Detect and Avoid and Contingency Management
  - Ran on hardware used by flight vehicles
- Measuring Performance for Autonomy Teaming with Humans (MPATH)
  - GCSO's ground station interface with vehicles
  - Used to issue commands and provide data to vehicle
  - Developed by NASA for human factors data collection
  - Enhanced by HDV to handle interactions with ICAROUS and Safe2Ditch
- Multi Aircraft Control System (MACS)
  - Simulated aircraft to help provide large amounts of operations with the HHITL simulation vehicles

Simulation Setup – Components Cont.

- High Density Vertiplex (HDV) client
  - Main interface for interaction with the HDV prototype UAM ecosystem
  - Provided the tabs for operations, scheduling, vertiports and a map
  - Used by VM, FM and GCSOs to plan, coordinate, and execute operations
  - Contained the Trial Planner for FM operation replanning
- Vertiport Automation System (VAS)
  - Supported VM role by handling operation requests involving their vertiport
  - Automatic operation approval or denials based on vertiport status
  - Automatic landing approval and denials on vehicle approach
- Integrated Airspace Display (IAD)
  - Provided a shared display of vehicles within the area of operation
- UAS Mission Analysis Tool (UMAT)
  - Provided a three-dimensional view of the vertiport operational area
  - Allowed the VM to monitor arrival and departures to spot conflicts

Scenarios

- Nominal
  - All vehicles fly their mission without issue
  - No operation or landing denials
- Missed Approach
  - Vehicle required to loop around after approach to clear space for a vehicle behind it
- Speed Change
  - Short vertipad closure, FM commanded a speed change for GCSOs
  - This slowed arrival time until vertipad opens again
- Divert
  - Long vertipad closure, FM re-routed vehicles to a new vertiport using the Trial Planner
  - GCSO updated vehicle's flight plan with new plan generated by FM
- Combination of Missed Approach, Divert, and Speed Change.
  - Long vertiport closure required FM to issue a missed approach command, divert vehicles and change vehicle speeds

Human Factors Data Collection

- Collected a variety of data on the different roles to evaluate
  - Workload
  - Trust
  - Situational Awareness
  - Risk Assessments
- Each Role partook in
  - Pre and Post Session Questionnaires
  - Post scenario questionnaires
  - After Action Reviews after all simulations completed

Takeaways

- Landing Denial Resolution
  - GCSO required FM to resolve the conflict of a denied landing
  - If FM missed the denied landing, GCSO would have no action to take within the HDV prototype UAM ecosystem to resolve the conflict
- Implementation of the prototype UAM ecosystem
  - Implementation and execution of this ecosystem required careful planning
  - Schedules of each integration test and simulation day provided to team advance
- Standard Approach Speeds
  - Vehicles approached along the same approach path, but at different speeds
  - Standard approach speed would have helped ensure vehicles did have a loss of separation

Takeaways Cont.

- Detect and Avoid Lookahead time
  - ICAROUS lookahead time was 20 seconds, but this projected out too far
  - GCSOs saw indications of conflict without knowing why
- Takeoff and Landing Buffers for vertipads
  - The VAS did not consider taxi time when approving takeoff and landing windows
  - Led to vehicles taking off and landing very closely to each other, causing a loss of separation

Follow on Work

- HDV PAO Flight
  - Transition of the HDV prototype UAM ecosystem from simulation to flight operations using Free Fly Alta 8 Pro multirotor vehicles
  - Used the same scenarios as this simulation, but with up to five GCSOs
- HDV BVLOS Training
  - Training developed by HDV for remote sUAS piloting
  - Using the prototype UAM ecosystem components to train GCSOs
  - Developed scenarios using the HHITL simulation to simulated different off-nominal situations
- HDV BVLOS flight
  - Conducted flight operations with no visual observer
  - Surveillance systems setup around flight range and provided to the IAD to provide airspace awareness to roles in ROAM

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