Ontology Foundation for RL-Constrained Drone Autonomy

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1 Ontology Foundation for RL-Constrained Drone Autonomy

Purpose: Define canonical problems and domain vocabulary for Flyby F-11 autonomous missions using SUMO ontology framework.

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1.1 Part 1: Canonical Problems

1.1.1 Problem Definition Template

For each canonical problem, specify: 1. **Mission objective** (what success looks like) 2. **Initial conditions** (starting state, environment assumptions) 3. **Constraints** (safety bounds, operational

limits, no-fly zones) 4. **Termination conditions** (mission complete, failure cases, timeout) 5. **Evaluation metrics** (how to measure performance)

1.1.2 Canonical Problem 1: [NAME]

Mission Objective: - [ ] TODO: Define what the drone must accomplish

Initial Conditions: - [ ] TODO: Starting position (ground, airborne) - [ ] TODO: Environment (indoor, outdoor, obstacles present/absent) - [ ] TODO: Sensor state (GPS available, visual odometry only, etc.)

Constraints: - [ ] TODO: Safety constraints (min/max altitude, geofence boundaries) - [ ] TODO: Operational constraints (battery reserve, time limits) - [ ] TODO: Environmental constraints (weather, lighting, obstacles)

Termination Conditions: - [ ] TODO: Success criteria (reached goal, task completed) - [ ] TODO: Failure criteria (collision, lost localization, timeout) - [ ] TODO: Abort criteria (low battery, lost communication)

Evaluation Metrics: - [ ] TODO: Task completion rate - [ ] TODO: Time to completion - [ ] TODO: Energy efficiency - [ ] TODO: Safety violations (constraint breaches) - [ ] TODO: Other domain-specific metrics

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1.1.3 Canonical Problem 2: [NAME]

Mission Objective: - [ ] TODO:

Initial Conditions: - [ ] TODO:

Constraints: - [ ] TODO:

Termination Conditions: - [ ] TODO:

Evaluation Metrics: - [ ] TODO:

1.1.4 Canonical Problem 3: [NAME]

Mission Objective: - [ ] TODO:

Initial Conditions: - [ ] TODO:

Constraints: - [ ] TODO:

Termination Conditions: - [ ] TODO:

Evaluation Metrics: - [ ] TODO:

1.1.5 Additional Problems

☐ TODO: Add more canonical problems as needed (recommend 3-7 total)

1.2 Part 2: Domain Vocabulary

1.2.1 Vocabulary Template

For each concept, specify: 1. **SUMO parent class** (how it relates to existing SUMO hierarchy) 2. **Definition** (formal description of the concept) 3. **Attributes/Properties** (relevant features or parameters) 4. **Relations** (how it connects to other concepts) 5. **Instances/Examples** (concrete examples in our domain)

1.2.2 Concept Category: Physical Objects

1.2.2.1 Concept: UAV (Unmanned Aerial Vehicle)

SUMO Parent Class: - [ ] TODO: Identify parent (likely `Device` → `TransportationDevice` or similar)

Definition: - [ ] TODO: Formal definition of what constitutes a UAV in our domain

Attributes: - [ ] TODO: Mass, dimensions, payload capacity, battery capacity, flight time - [ ] TODO: Sensor suite (cameras, depth sensors, IMU, GPS, etc.) - [ ] TODO: Actuators (motors, propellers, control surfaces)

Relations: - [ ] TODO: `carries` (payload, sensors) - [ ] TODO: `locatedAt` (spatial position) - [ ] TODO: `hasState` (flight phase, battery level, etc.)

Instances: - [ ] TODO: FlybyF11 (our specific platform)

1.2.2.2 Concept: Obstacle

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.2.3 Concept: Target/Waypoint

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.3 Concept Category: Spatial Relations

1.2.3.1 Concept: Above/Below

SUMO Parent Class: - [ ] TODO: Likely `PositionalAttribute` or `SpatialRelation`

Definition: - [ ] TODO: Formal definition with thresholds (e.g., "Above(X, Y) iff altitude(X) > altitude(Y) + threshold")

Attributes: - [ ] TODO: Vertical separation distance

Relations: - [ ] TODO: Binary relation between physical objects

Instances: - [ ] TODO: UAV above ground, UAV above obstacle

1.2.3.2 Concept: Near/Far

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.4 Concept Category: Processes (Actions/Behaviors)

1.2.4.1 Concept: Takeoff

SUMO Parent Class: - [ ] TODO: Likely `Process` or `Motion`

Definition: - [ ] TODO: Transition from ground state to airborne state

Attributes: - [ ] TODO: Target altitude, ascent rate

Relations: - [ ] TODO: `precondition` (battery sufficient, motors armed) - [ ] TODO: `postcondition` (altitude > threshold, airborne state) - [ ] TODO: `during` (vertical ascent, stabilization)

Instances: - [ ] TODO: Standard takeoff, emergency takeoff

1.2.4.2 Concept: Navigation/Waypoint Transit

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.4.3 Concept: Loiter/Hover

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.4.4 Concept: Landing

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.5 Concept Category: States

1.2.5.1 Concept: FlightPhase

SUMO Parent Class: - [ ] TODO: Likely `StateOfMind` or custom `StateAttribute`

Definition: - [ ] TODO: Discrete states representing mission progression

Attributes: - [ ] TODO: Current phase (e.g., preflight, takeoff, cruise, mission, landing, emergency)

Relations: - [ ] TODO: `transitions_to` (valid state transitions) - [ ] TODO: `requires` (conditions for entering state)

Instances: - [ ] TODO: Preflight, Armed, Airborne, Mission, RTL (Return to Launch), Emergency

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1.2.5.2 Concept: BatteryState

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.6 Concept Category: Safety Constraints

1.2.6.1 Concept: GeofenceBoundary

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.6.2 Concept: MinimumAltitude

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.6.3 Concept: BatteryReserve

SUMO Parent Class: - [ ] TODO:

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO:

1.2.7 Concept Category: Temporal Relations

1.2.7.1 Concept: Before/After/During

SUMO Parent Class: - [ ] TODO: `TemporalRelation`

Definition: - [ ] TODO:

Attributes: - [ ] TODO:

Relations: - [ ] TODO:

Instances: - [ ] TODO: Takeoff before mission, landing after mission complete

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1.2.8 Additional Vocabulary Categories

- ☐ TODO: Add sensor concepts (camera, depth sensor, IMU, GPS)
- ☐ TODO: Add perception concepts (object detection, localization, mapping)
- ☐ TODO: Add mission-specific concepts (inspection, reconnaissance, monitoring)
- ☐ TODO: Add environmental concepts (weather, lighting, wind)

1.3 Part 3: Integration with RL

1.3.1 How Ontology Constrains RL (To Be Filled After Part 1 & 2)

State Abstraction: - [ ] TODO: Which ontology concepts map to RL state representation?

Action Space: - [ ] TODO: Which ontology processes define valid actions?

Reward Shaping: - [ ] TODO: Which ontology constraints contribute to reward penalties?

Hard Constraints: - [ ] TODO: Which ontology rules must never be violated (safety-critical)?

1.4 Notes for Discussion with Adam Pease

- ☐ TODO: Questions about SUMO subset selection
- ☐ TODO: Reasoning engine recommendations (Pellet, HermiT, custom)
- ☐ TODO: Performance considerations for real-time UAV constraints
- ☐ TODO: How to formally verify ontology constraint compliance
- ☐ TODO: Validation methodology for ontology completeness