Run-time Assurance for UAVs using Stochastic Modeling and Reachability Analysis

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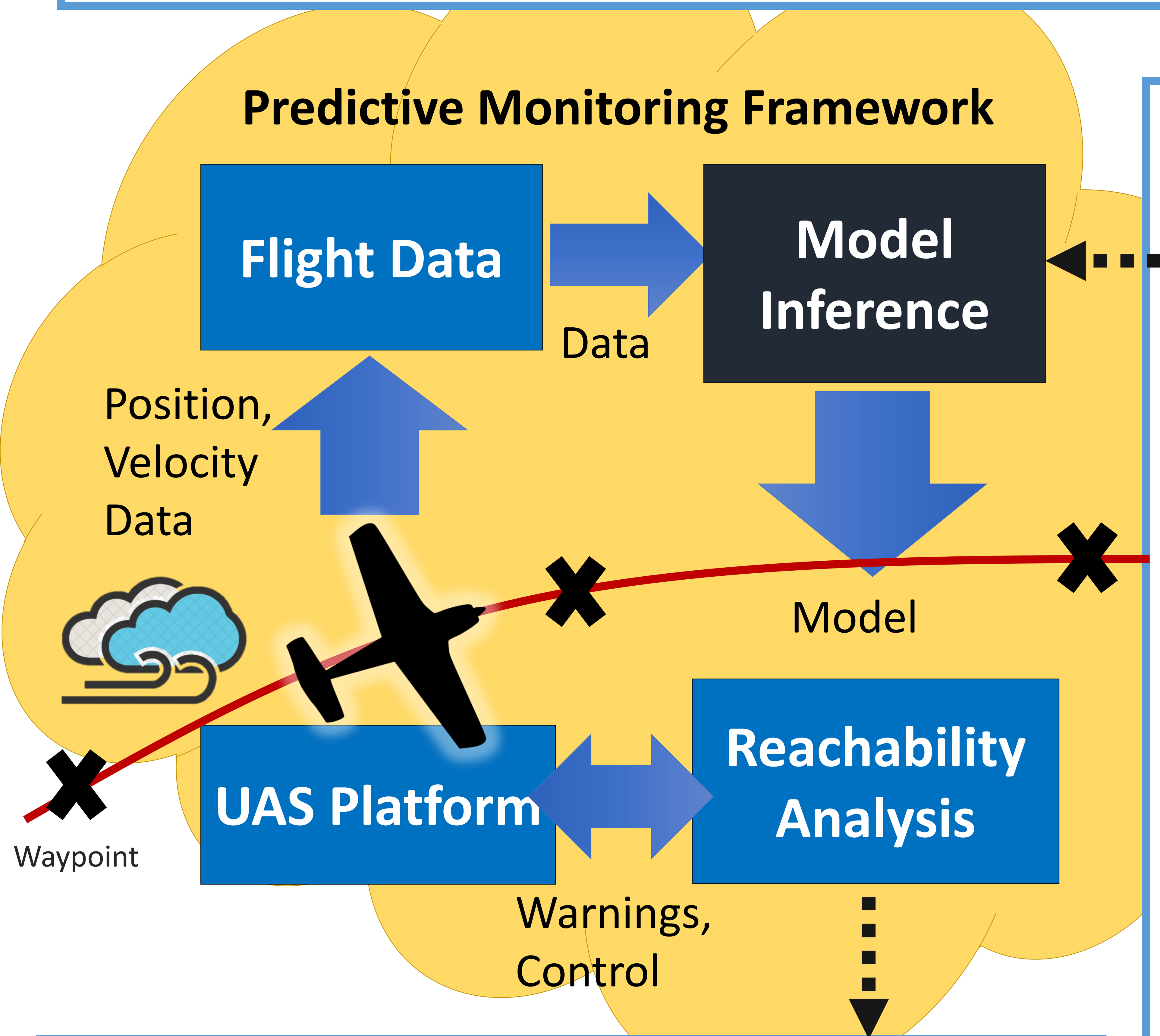
Motivation

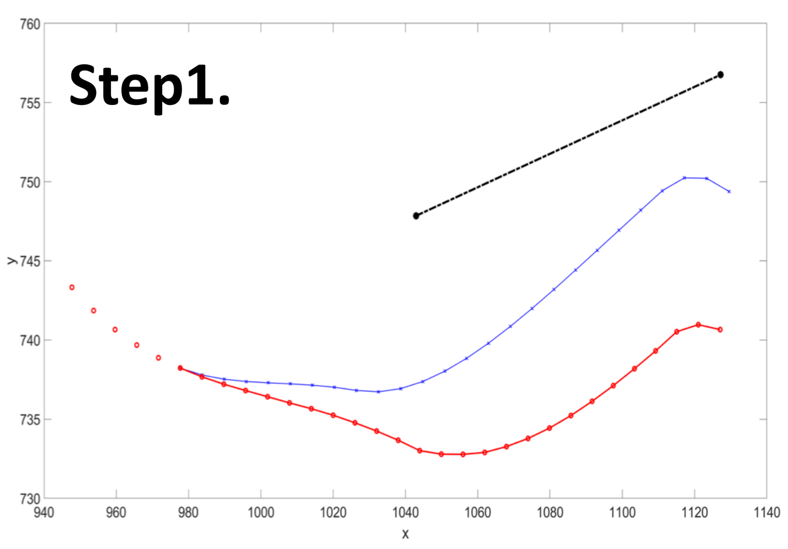
Proving that UAVs satisfy safety properties such as absence of collision with fixed obstacles is important because mission failure may cause loss of life and property. However, it is a hard to predict in advance due to unknown disturbance and unknown future control actions.

Can we predict future trajectory of UAVs in time horizon [0, T] to predict future collisions?

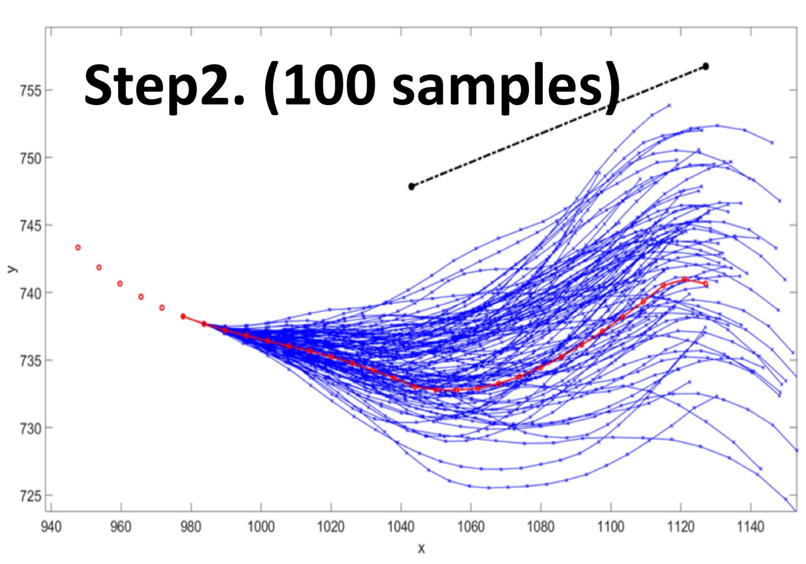
Objectives

1. Forecast future UAVs positions under disturbances.
2. Quantify risk of collisions with fixed obstacles.





Guidance Algorithm



Trajectory Prediction with disturbance model

Future States Prediction Model

Core position model

$$x(t+h) = x(t) + hv_x(t) + 0.5h^2 a_x + e_x(t+h)$$
$$y(t+h) = y(t) + hv_y(t) + 0.5h^2 a_y + e_y(t+h)$$
$$z(t+h) = z(t) + hv_z(t) + 0.5h^2 a_z + e_z(t+h)$$

Future Velocity Forecast sub-model

$$v_x(t+h) = v_x(t) + ha_x(t) + e_{vx}(t+h)$$
$$v_y(t+h) = v_y(t) + ha_y(t) + e_{vy}(t+h)$$
$$v_z(t+h) = v_z(t) + ha_z(t) + e_{vz}(t+h)$$

Deviation/Disturbance sub-model

(Ridge regression or Bayesian inference)

$$e(t+h) = \sum_{i=1}^{p} \omega_i e(t-(i-1)h) + \varepsilon(t+h)$$

Computation time for 100 samples: 6 secs

Waypoint Guidance Algorithm

Desired Acceleration

Future Waypoints

Collision Prediction Results

Evaluation on Talon UAV flight test data

Prediction \ Real	SAFE	COLLISION
SAFE	94	0
COLLISION	5	94
NOT SURE	1	6

* Test conditions: 3 m/s wind speed,
25 secs prediction time horizon,
0.4 collision probability cutoff threshold

Evaluation on Ardupilot simulator data

Prediction \ Real	SAFE	COLLISION
SAFE	93	10
COLLISION	6	94
NOT SURE	1	0

* Same test conditions but 5 m/s wind speed