

HALO: Hazard-Aware Landing Optimization (for Autonomous Systems)

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October 1, 2024

ICRA
L O N D O N · 2 0 2 3



A wide-angle photograph of a desert landscape. The foreground is a sandy, rocky plain with scattered dark rocks and some faint tracks. In the center, a large, dark, curved object, possibly a piece of fabric or a net, lies on the ground. The background shows a vast, flat desert extending to a hazy horizon under a bright, clear sky. The overall color palette is dominated by warm, earthy tones of sand and rock.

Introduction

Problem Statement

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Objective

Develop a framework that enables autonomous aerial vehicles to land *safely* in *unknown* environments with only *depth* information on their surroundings.

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Contributions

Two key algorithms developed and integrated (closed-loop) in the **AirSim** simulation environment:

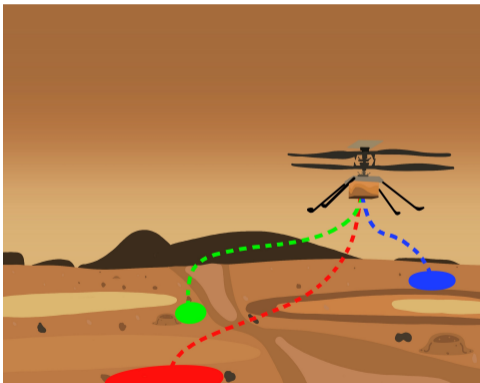
1. **Hazard-Aware Landing Site Selection (HALSS)**
2. **Adaptive Deferred-Decision Trajectory Optimization (Adaptive-DDTO)**

Problem Motivation

Introduction



Mars helicopter

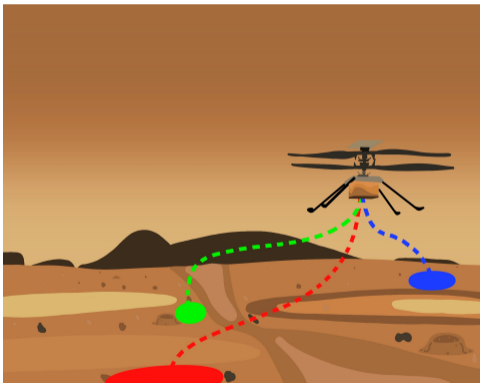


Problem Motivation

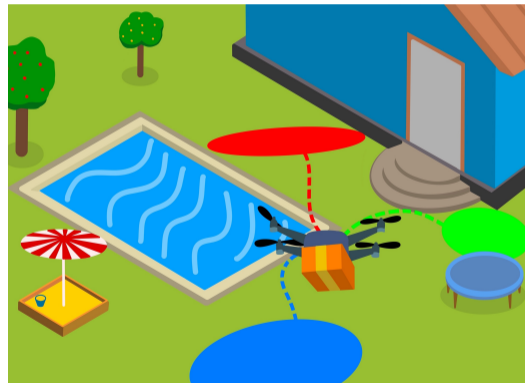
Introduction



Mars helicopter



Package delivery

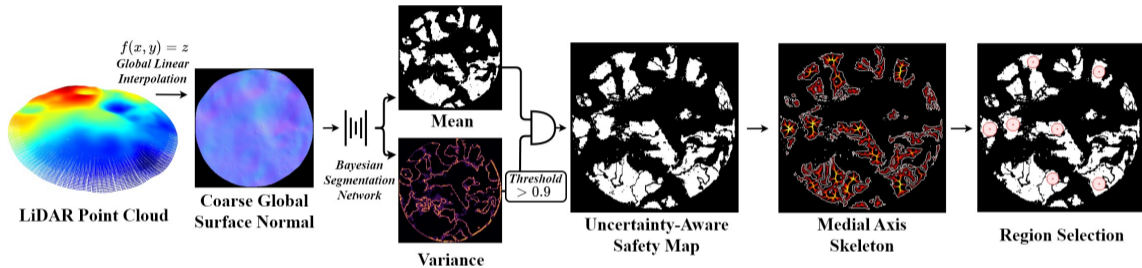




HALSS
Hazard-Aware Landing Site Selection

Coarse Hazard Detection

Hazard Aware Landing Site Selection

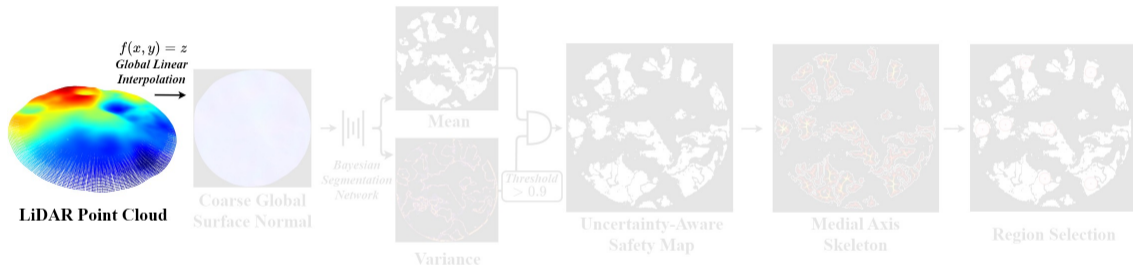


Overview

Perform a coarse search over all the observed map, use a learning-based approach to classify safety, and identify regions to further search for landing sites.

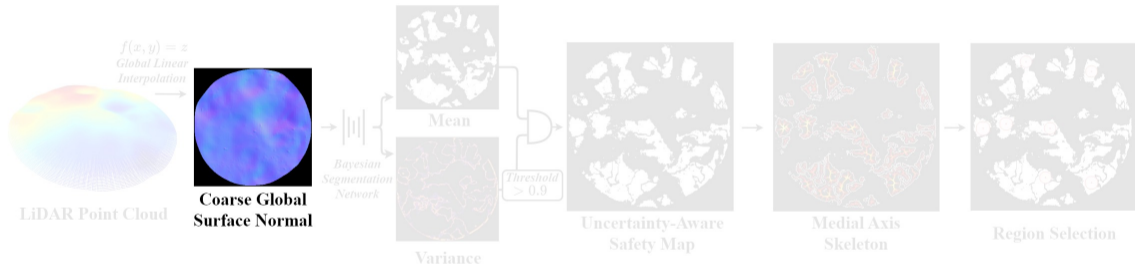
Coarse Hazard Detection: Point Cloud Interpolation

Hazard Aware Landing Site Selection



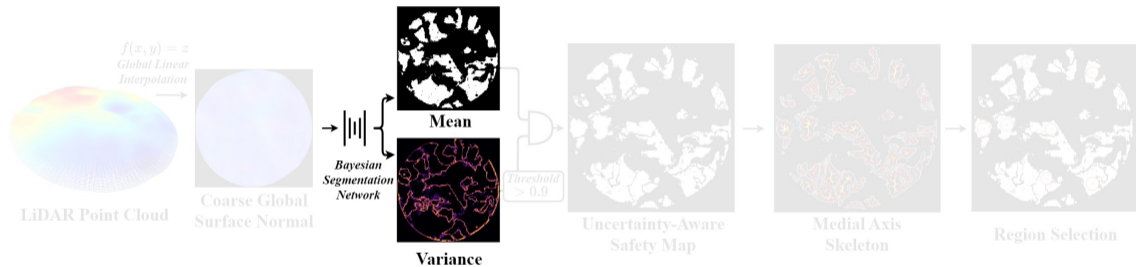
Coarse Hazard Detection: Surface Normal

Hazard Aware Landing Site Selection



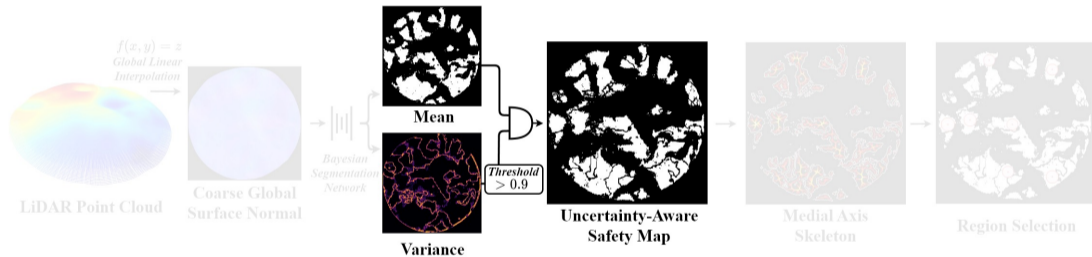
Coarse Hazard Detection: Bayesian Segmentation Network

Hazard Aware Landing Site Selection



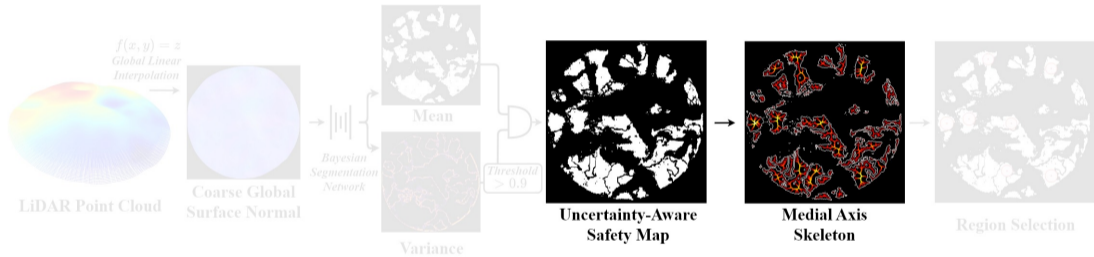
Coarse Hazard Detection: Variance-Aware Safety Map

Hazard Aware Landing Site Selection



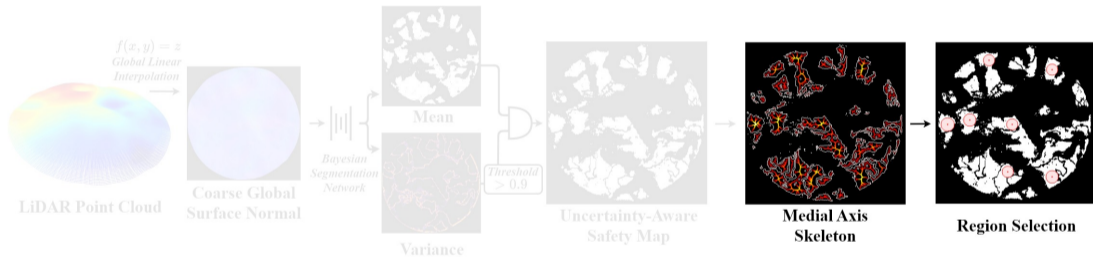
Coarse Hazard Detection: Medial Axis Transform

Hazard Aware Landing Site Selection



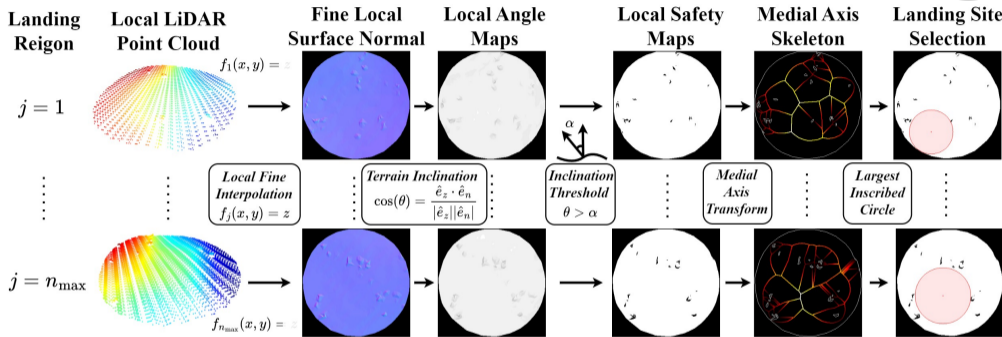
Coarse Hazard Detection: Region Selection

Hazard Aware Landing Site Selection



Fine Hazard Detection

Hazard Aware Landing Site Selection

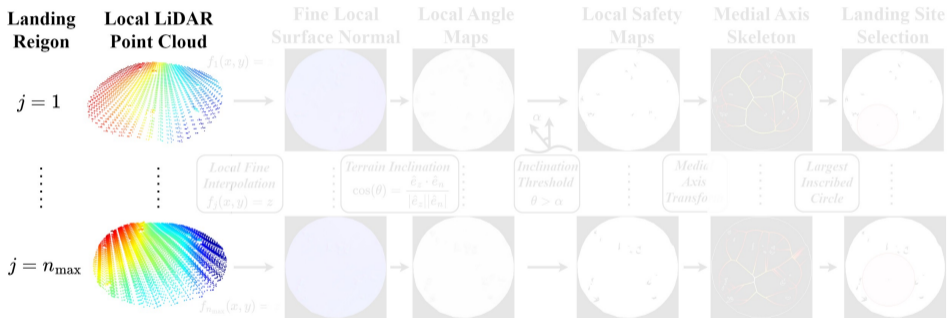


Overview

Given prospective regions, perform a fine search within each region, use a topographical-based approach to classify safety, and identify landing sites.

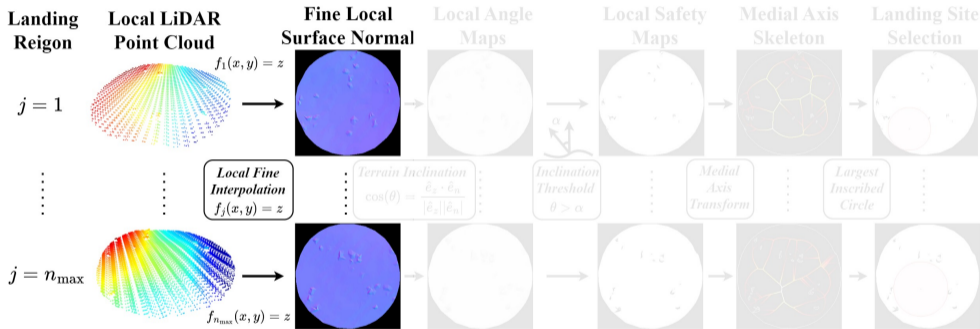
Fine Hazard Detection: Local LiDAR Resampling

Hazard Aware Landing Site Selection



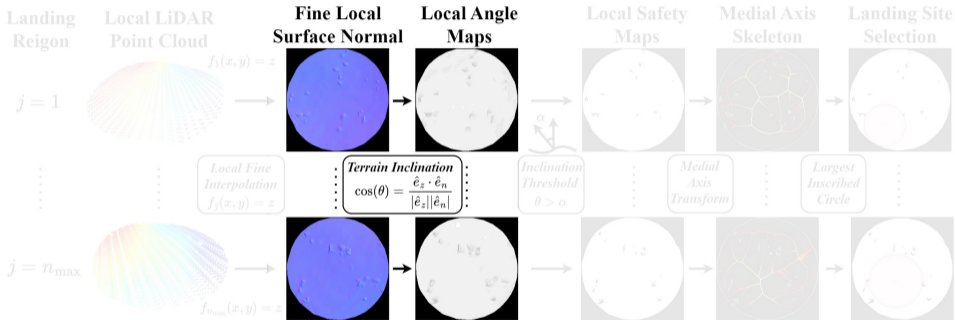
Fine Hazard Detection: Local Surface Normal

Hazard Aware Landing Site Selection



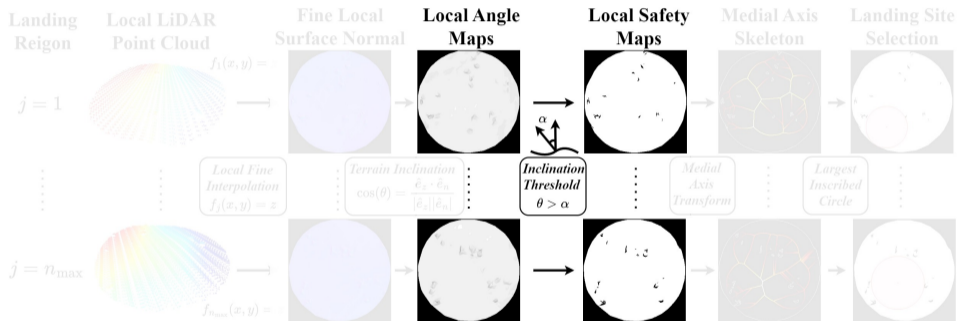
Fine Hazard Detection: Local Angle Map

Hazard Aware Landing Site Selection



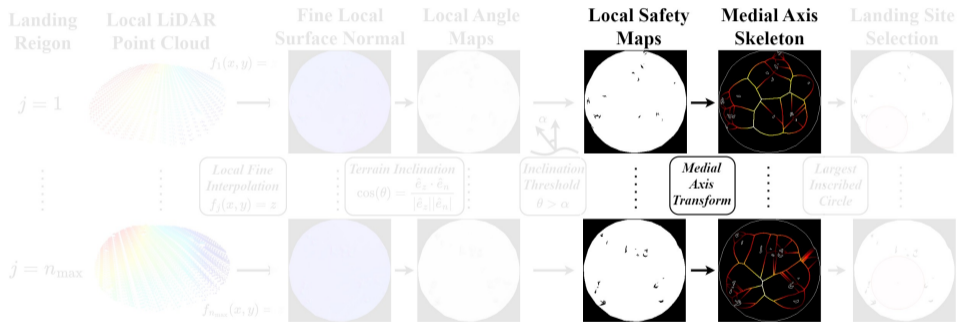
Fine Hazard Detection: Local Safety Map

Hazard Aware Landing Site Selection



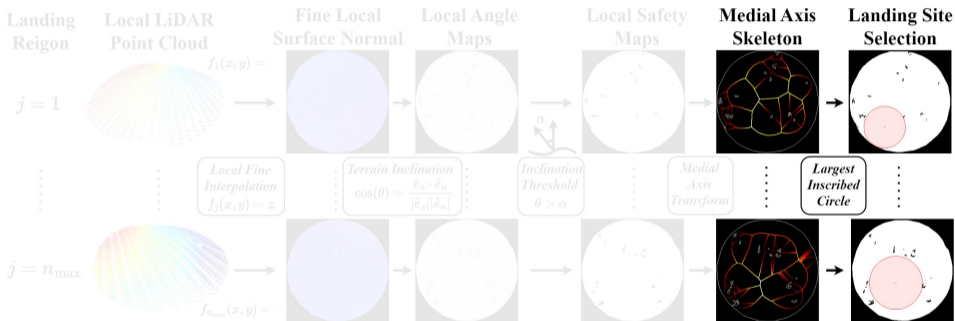
Fine Hazard Detection: Local Medial Axis Transform


Hazard Aware Landing Site Selection



Fine Hazard Detection: Landing Site Selection

Hazard Aware Landing Site Selection

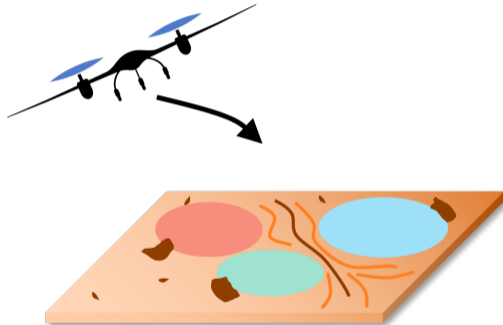




Adaptive-DDTO
Adaptive Deferred-Decision Trajectory Optimization

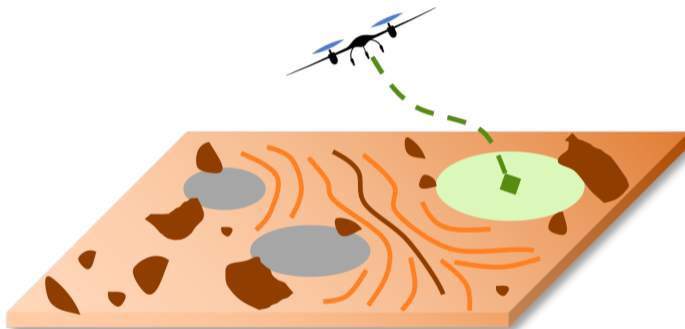
High-Level Approach

Adaptive-DDTO



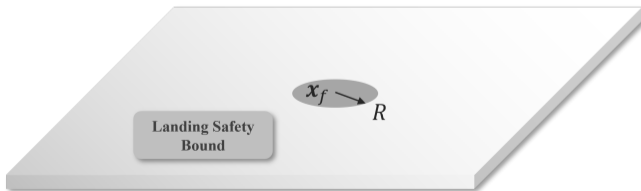
High-Level Approach

Adaptive-DDTO



Single-Target Trajectory Optimization

Adaptive-DDTO



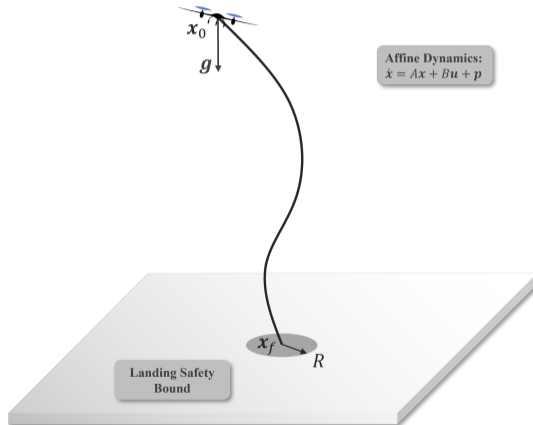
Single-Target Trajectory Optimization

Adaptive-DDTO



Objective:
 $\min \int \|T\|_2 dt$

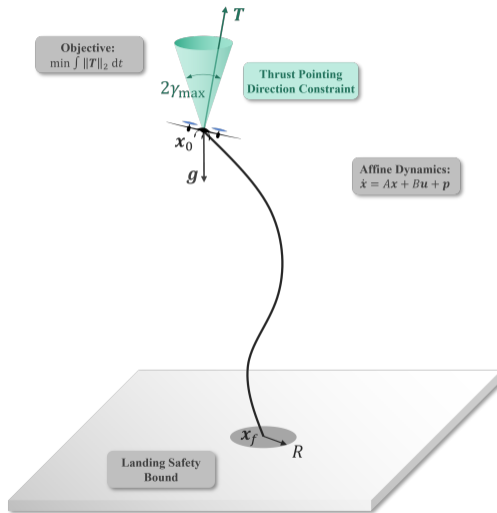
Affine Dynamics:
 $\dot{x} = Ax + Bu + p$



Landing Safety
Bound

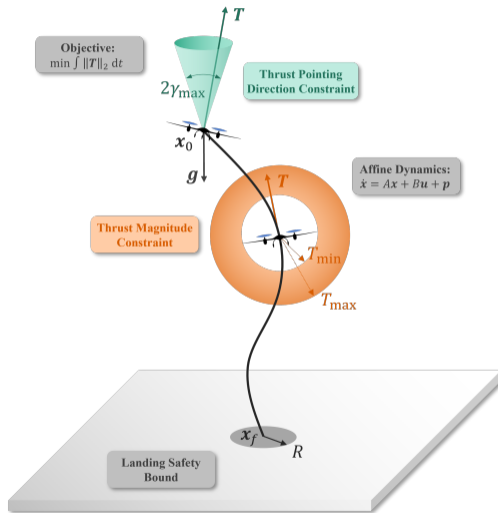
Single-Target Trajectory Optimization

Adaptive-DDTO



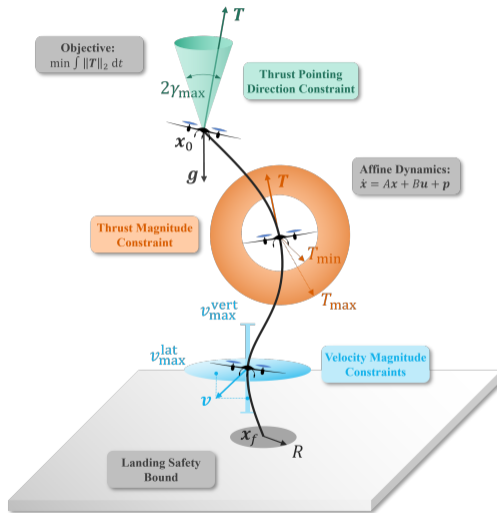
Single-Target Trajectory Optimization

Adaptive-DDTO



Single-Target Trajectory Optimization

Adaptive-DDTO



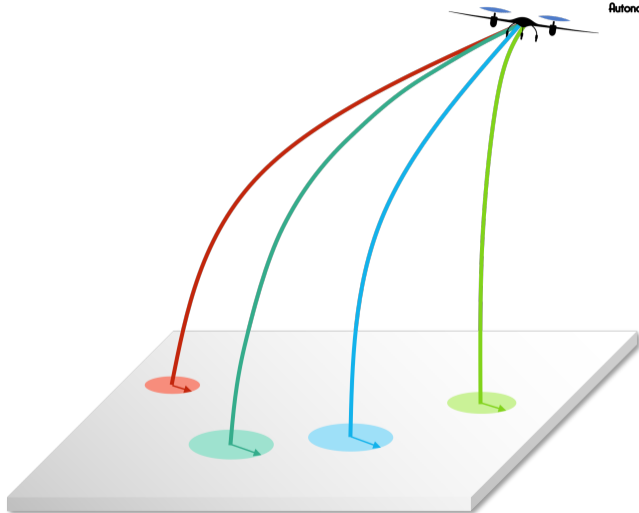
Deferred-Decision Trajectory Optimization (DDTO)

Adaptive-DDTO



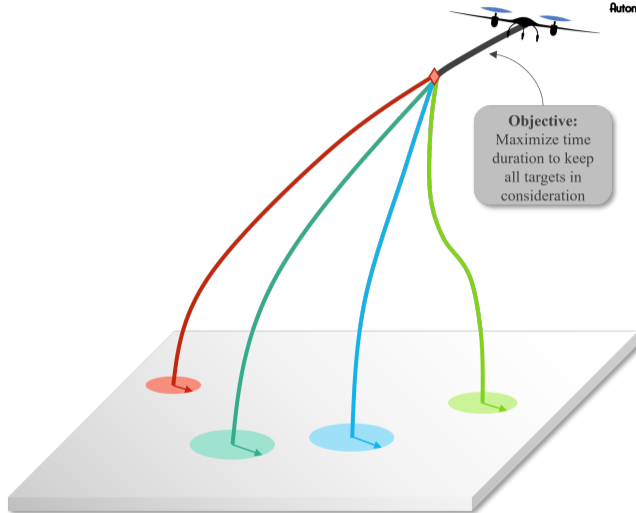
Deferred-Decision Trajectory Optimization (DDTO)

Adaptive-DDTO



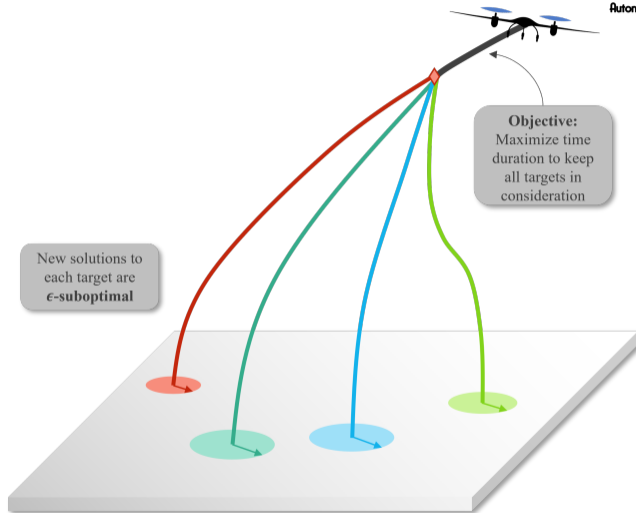
Deferred-Decision Trajectory Optimization (DDTO)

Adaptive-DDTO



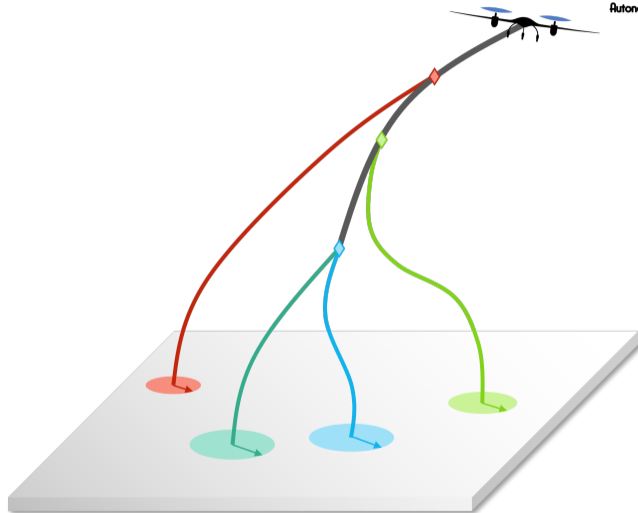
Deferred-Decision Trajectory Optimization (DDTO)

Adaptive-DDTO



Deferred-Decision Trajectory Optimization (DDTO)

Adaptive-DDTO



Deferred-Decision Trajectory Optimization (DDTO)

Adaptive-DDTO



Problem

Targets can be lost while executing solution due to:

1. Perception updates
2. Dynamic changes in the environments
3. DDTO's tree-like structure

Deferred-Decision Trajectory Optimization (DDTO)

Adaptive-DDTO



Problem

Targets can be lost while executing solution due to:

1. Perception updates
2. Dynamic changes in the environments
3. DDTO's tree-like structure

Solution

Adaptively recompute DDTO solutions whenever target count falls below a minimum threshold.

A simulated Mars landscape with a rover's tracks and solar panels. The terrain is reddish-brown and rocky, with a clear sky. The text "Simulation Results" is overlaid in the center.

Simulation Results



 **GitHub**.com/UW-ACL/HALO

Thanks for watching!

Extra Acknowledgements:

- Annika Singh
- Purnanand Elango
- National Science Foundation Graduate Research Fellowship Program (NSF GRFP)

I C R A
L O N D O N · 2 0 2 3



Autonomous Controls Laboratory (ACL)
Controls & Trustworthy Robotics Laboratory (CTRL)