Autonomous Exploration through Heterogeneous Robotic Collaboration

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Objective & Motivation

Objective:
- Building a collaborative heterogeneous robot fleet capable of autonomous exploration of Mars' environment.

Motivation:
- Human controlled navigation suffers from long latencies and limited reaction time.
- Heterogeneous agents having different capabilities can enable collaboration and more efficient information sharing for exploring the surroundings, which otherwise would be impossible for a single/homogeneous robot system.
- Collaboration can unlock new abilities/optimisation for the robot system.

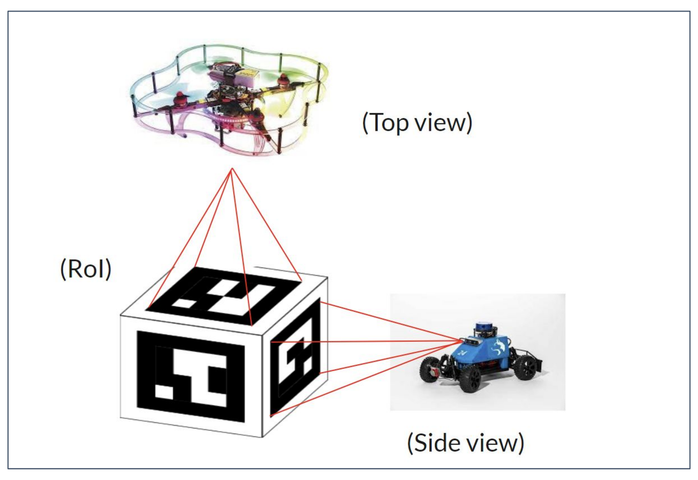
System Architecture

To meet our mission objectives, we have chosen a heterogeneous system comprising of a rover and a drone:

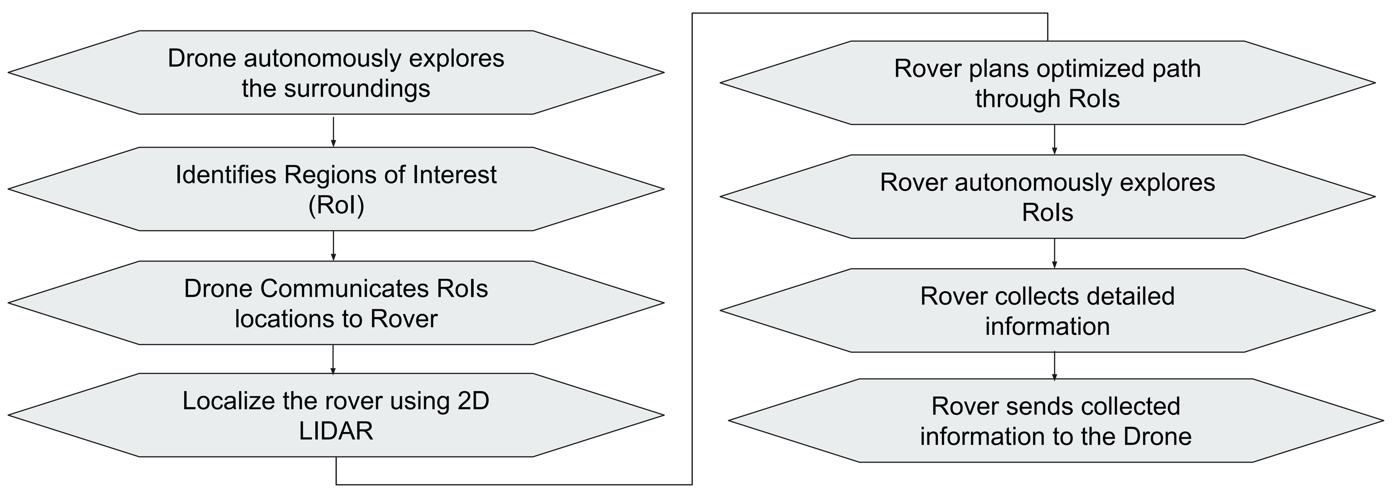
System configuration:
- Rover + Drone

Drone:
- Coex Clover (Platform)
- Birdview camera, range sensor
- Raspberry pi, WiFi AP.

Rover:
- MuSHR (Platform)
- RGBD camera, LIDAR
- Jetson Nano, WiFi, Bluetooth.



Workflow

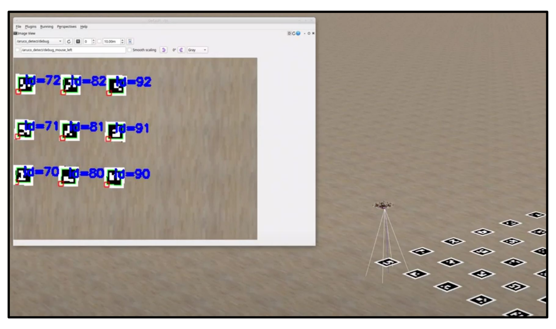


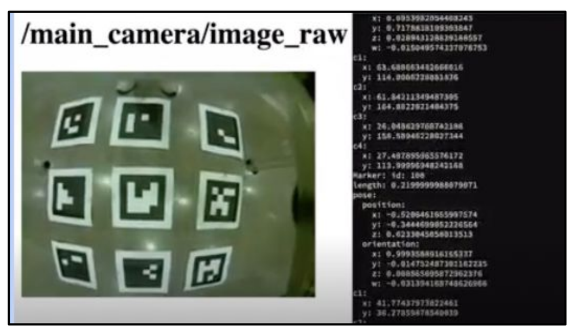
Collaboration

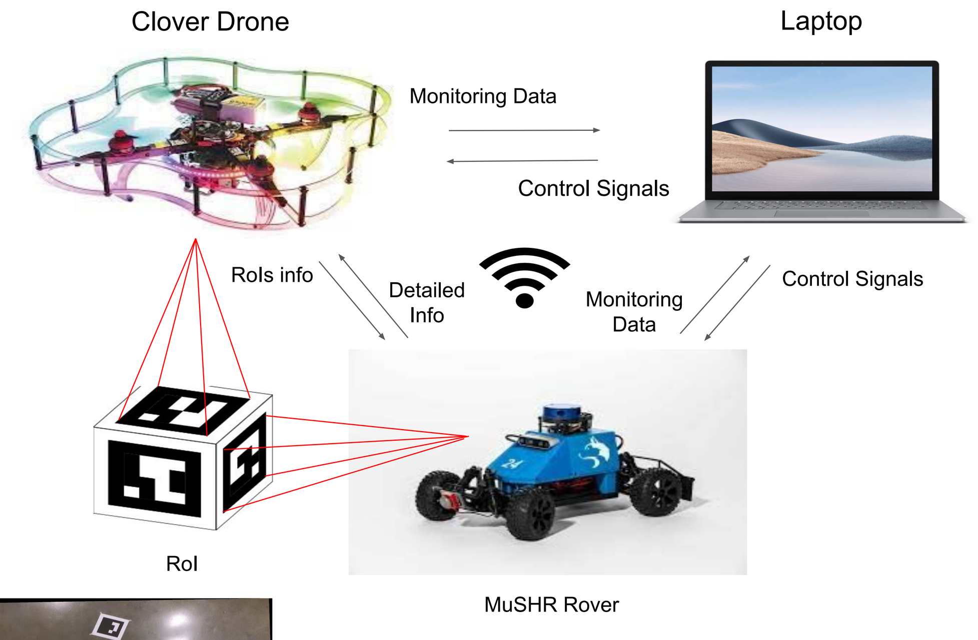
Drone:
- Establish WiFi network
- Establish ROS master
- Run modules

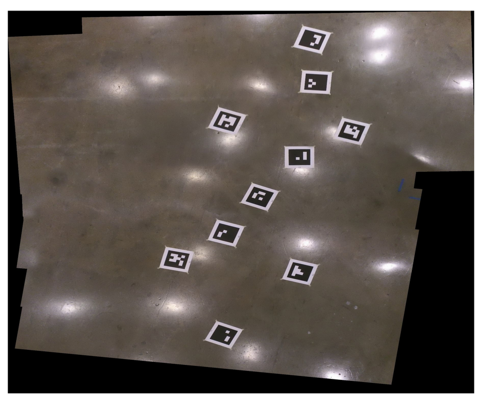
Rover:
- Connects to Drone's network
- Establish ROS host
- Run modules

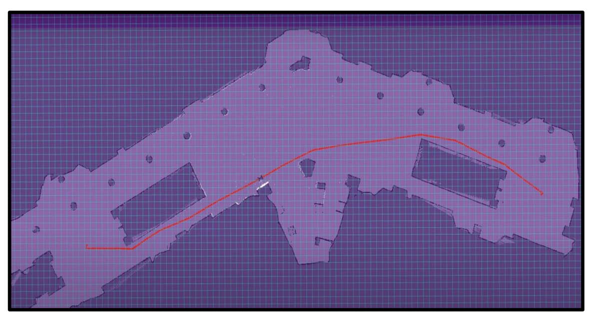
Laptop:
- Connects to Drone's network
- Control/Monitor the drone and rover











Modules Description

Drone control module:
- Navigates the drone to explore the environment autonomously.

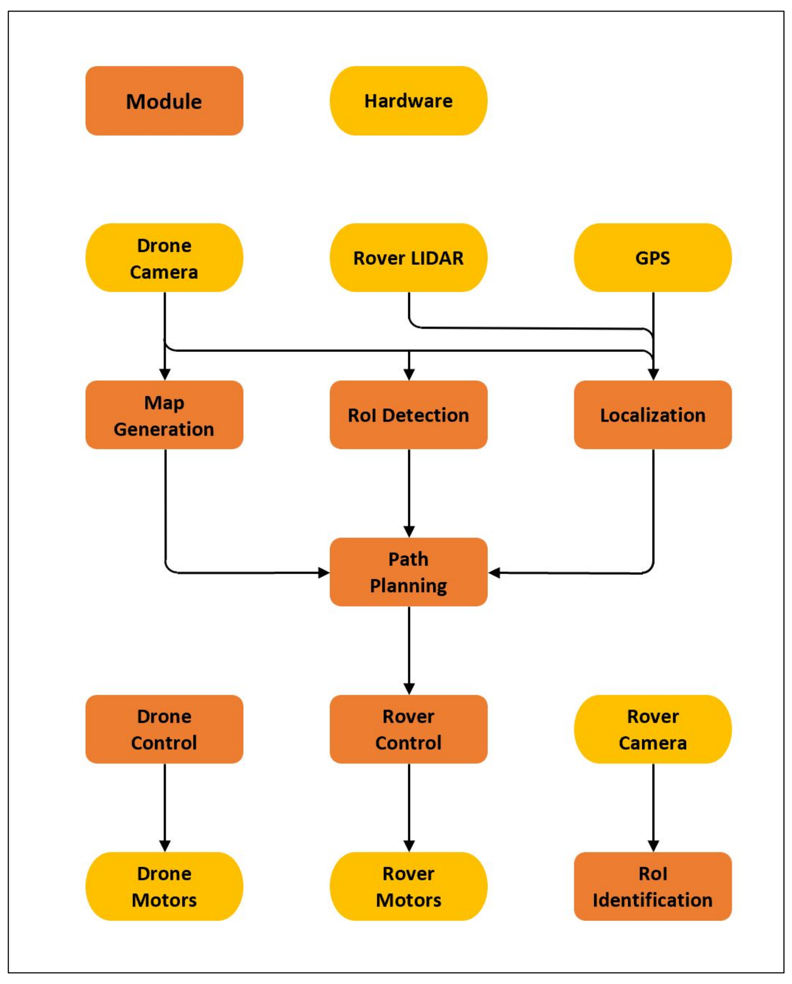
Map generating module:
- Creates map using drone's camera feed and identifies ArUco markers which represent potential RoIs.

Rover localization module:
- Performs 2D LIDAR based rover localization using Particle filter algorithm.

Path planning module:
- Uses A* algorithm to plan an optimized path that covers all RoIs.

Rover control module:
- Navigates the rover through the optimised path.

Region of interest identification module:
- Identifies/Explores the surrounding regions in detail when the rover gets close to RoIs.



Summary and Evaluation

We have built a strong foundation for heterogeneous system that is capable of doing autonomous exploration in an unknown environment. The chosen platforms are highly programmable, have extensive support and capabilities to develop sophisticated collaboration.

Assumptions Constraints for the agents

- Drone : Limited flight height and localization.
- Rover : 2D LIDAR based rover localization using Particle filter algorithm.

Pipeline Simplifications

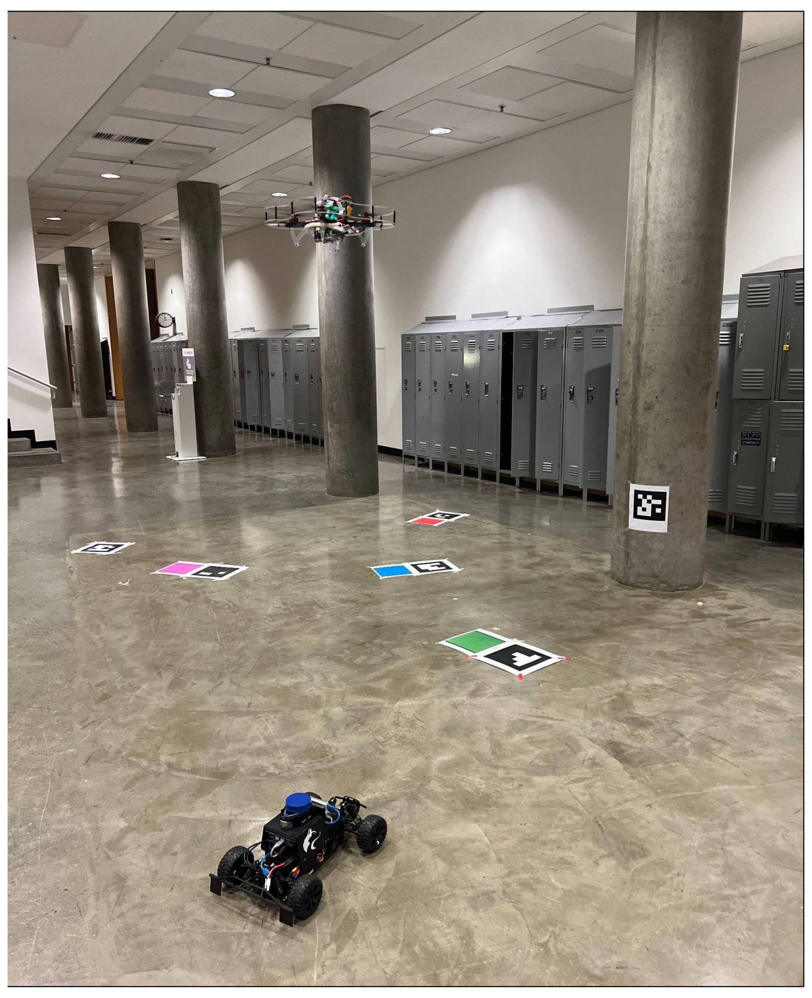
- Terrain
- Rover and Drone Localization
- Mapping
- Mobility
- Communication and data transfer

Capabilities Drone + Rover System for Mars Exploration

- Framework for exploration
- Open Source
- Sophisticated Collaboration

Evaluation System Comparison

	Homogenous (Baseline)	Heterogenous (Our system)	Improvement Factor
APC (in mw)	4462	9231	0.483
ACU (in %)	124	162	0.765
Time (in s)	150	98	1.530
Distance (in m)	120	46	2.609



* APC : Average Compute Power consumption | ACU: Average CPU usage | Improvement factor > 1 is better

Future Work & Reference

- Evaluate more relevant metrics and their sensitivity on exploration performance:
  - Confidence score for RoIs and agents.
  - Completeness and quality of built maps.
  - Collaborative map registration.
- Alternate methods for localization:
  - GPS, Image and optical flow localization.
- Develop more optimal exploration strategies for:
  - Efficient coordination.
  - Exploiting more functionalities.
  - Cost-benefit analysis.
- Incorporate more heterogeneous robots:
  - Increasing Redundancy and robustness.
- Improve large distance communication and data transfer:
  - Decrease latency
  - Decrease bandwidth usage/packet loss.
- Evaluating Deep learning models for more tolerant and robust detection.

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