Problem Domain: **Space Technology**

LunaBot: Autonomous Navigation of Robot for Lunar Habitats

PEC HACKS

ASTRO-NEER

Problem Statement

The Problem: Autonomous lunar navigation is hindered by high-risk, non-deterministic environments where traditional hard-coded pathfinding (like A*) cannot adapt to randomized hazards.

The system directly addresses critical challenges such as high astronaut workload on repetitive tasks, navigational difficulties in GPS-denied environments, and the inherent risks of human-led maintenance patrols.

Our solution is a unified robotics platform that leverages Swarm Collaboration and Predictive AI for adaptive and proactive maintenance.

The Goal: Moving from reactive collision avoidance to proactive path optimization through deep reinforcement learning (DRL).

Project LunaBot proposes an autonomous, multi-robot swarm system designed for the safe, efficient, and sustainable operation of lunar habitats.

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Problem Resolution

High astronaut workload for manual inspection and **repetitive tasks.**

Navigation challenges in complex, **GPS-denied environments.**

Safety risks and inefficiencies of human-led maintenance patrols.

Absence of a real-time Digital Twin **prevents predictive analysis** and proactive decision- making from Earth.

Lack of **continuous, real-time monitoring** of habitat integrity and life support.

Manual or **single-robot systems are inefficient** for larger, more complex future habitats and are not easily scalable.

Explanation of Solution

Autonomous Navigation

Swarm Collaboration

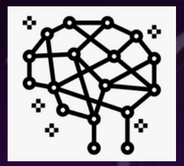
Habitat Monitoring

Digital Twin

Predictive AI

LunaBot

Robotic Swarm



ML Agents

Mission Control Dashboard

Unique Value Propositions

To deploy an autonomous multi-robot system for the safe, efficient, and sustainable operation of lunar habitats.

A unified robotics platform that improves operational efficiency and reduces long- term mission costs.

An intelligent system built on Swarm Collaboration and Predictive AI for adaptive and proactive maintenance.

Significantly reduced astronaut workload on manual tasks, enabling a greater focus on scientific research.

Dependencies

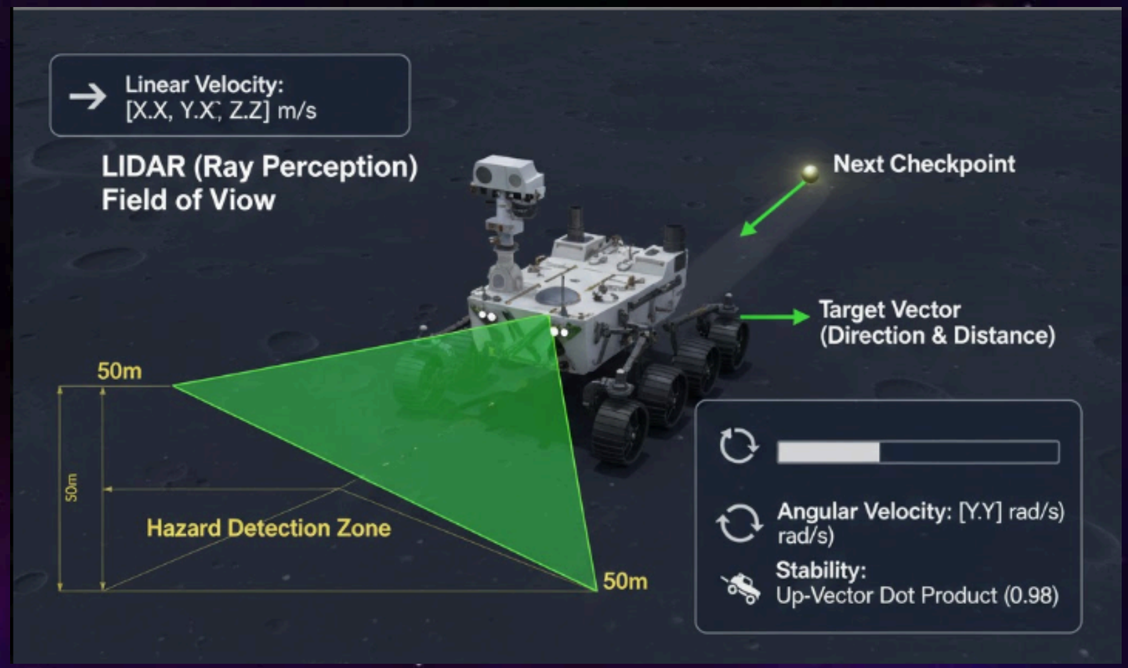
- ML Agents
- Ant Colony Optimization
- Unity
- A* Navigational Algorithm
- ORB-SLAM3
- OpenCV
- Python 3
- Linux
- YOLO

Agent Architecture: Observation Space

Agent Observation Space (12-D Vector)

Internal Telemetry & Vector Observations

- **Target Vector:**
  - Localized direction and distance to the next navigation checkpoint.
- **Inertial Data:**
  - Real-time 3D linear velocity
  - Angular Y-velocity (turning rate).
- **Stability Metrics:**
  - "Up-vector" dot product to detect vehicle roll.
  - Critical for preventing tip-over failures.
- **Perception (Visual Context):**
  - LIDAR Ray Perception (Field of View).
  - Hazard Detection Zone (50 m range)



Reward Policy

Reward Signal Structure

- **Dense Reward Signal (Performance):**
  - Progress Bonus: Delta-based rewards for decreasing distance to target (prevents agent "stalling").
  - Efficiency: -0.05 penalty for backtracking to ensure optimal energy usage.
- **Safety Penalties (Critical Failures):**
  - Collision: -10.0 penalty.
  - Tip-over: -5.0 penalty.
- **Intrinsic Motivation (Exploration):**
  - Curiosity Module: Strength factor of 0.02.
  - Rewards the agent for exploring new, unmapped terrain states rather than sticking to known paths.
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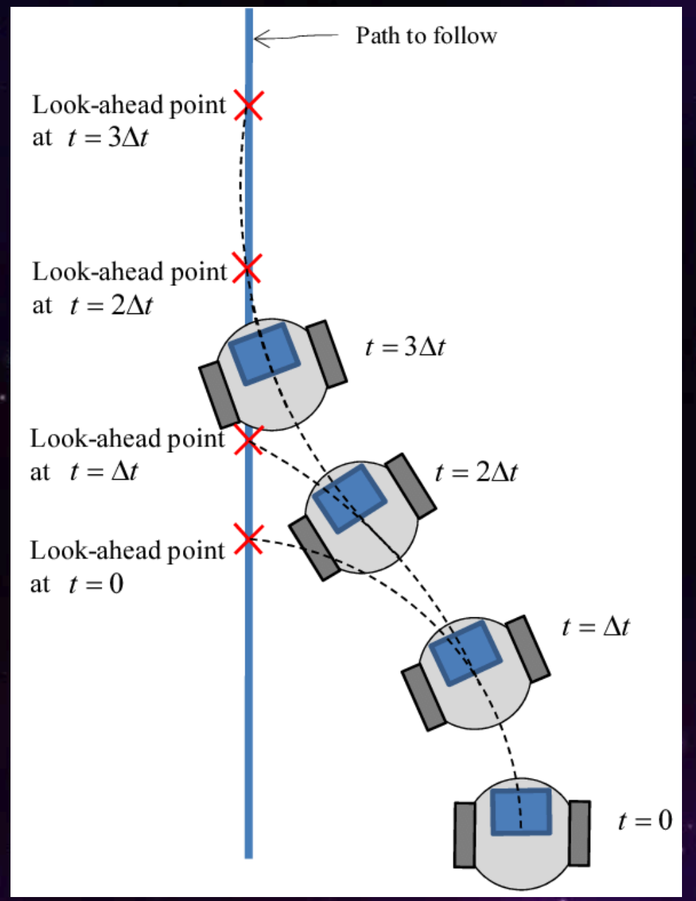
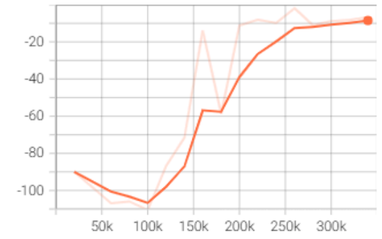
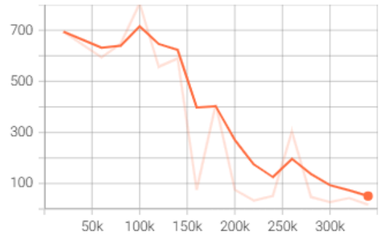


Environment

Cumulative Reward
tag: Environment/Cumulative Reward

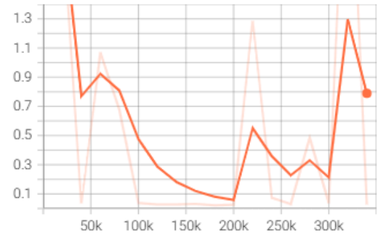


Episode Length
tag: Environment/Episode Length

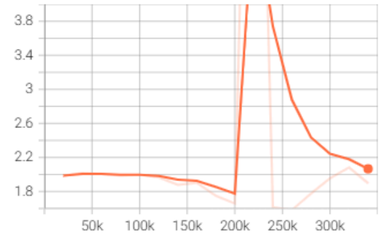


Losses

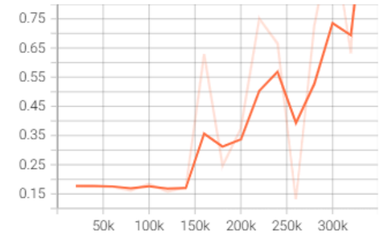
Curiosity Forward Loss
tag: Losses/Curiosity Forward Loss



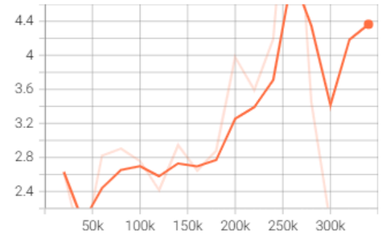
Curiosity Inverse Loss
tag: Losses/Curiosity Inverse Loss



Policy Loss
tag: Losses/Policy Loss

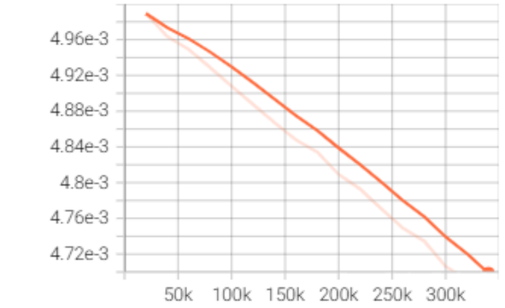


Value Loss
tag: Losses/Value Loss

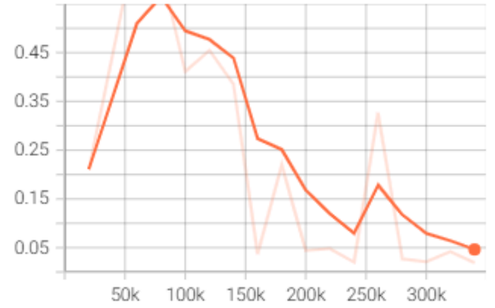


Policy

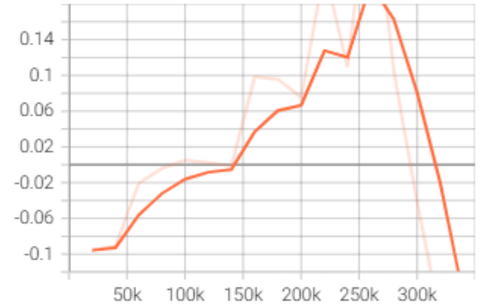
Beta
tag: Policy/Beta



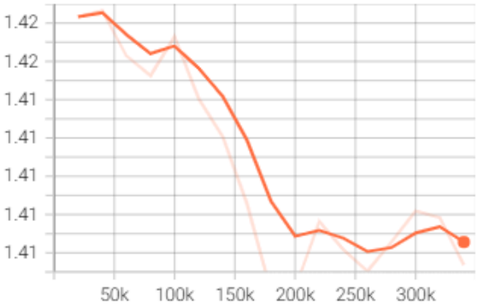
Curiosity Reward
tag: Policy/Curiosity Reward



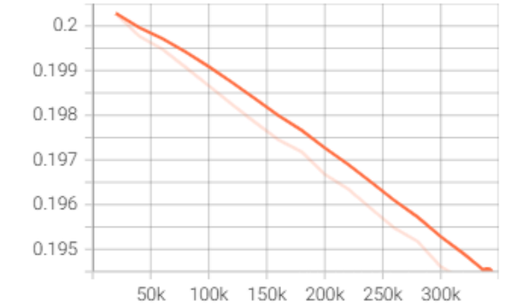
Curiosity Value Estimate
tag: Policy/Curiosity Value Estimate



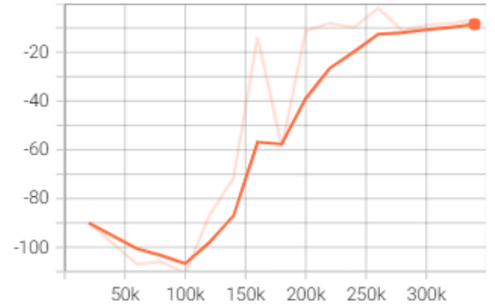
Entropy
tag: Policy/Entropy



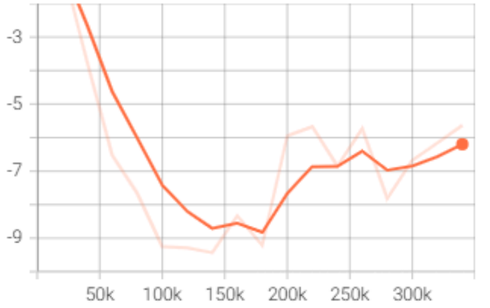
Epsilon
tag: Policy/Epsilon



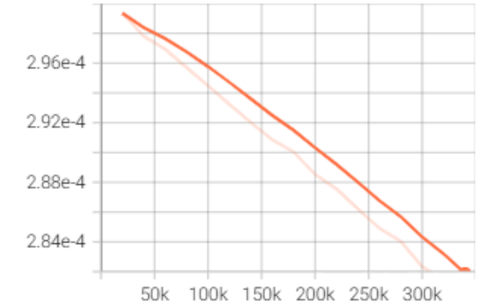
Extrinsic Reward
tag: Policy/Extrinsic Reward



Extrinsic Value Estimate
tag: Policy/Extrinsic Value Estimate



Learning Rate
tag: Policy/Learning Rate



LunaBot's **autonomous workforce** delivers the immediate benefit of making missions **drastically safer** and more **cost-effective**, which creates the foundational impact of a **sustainable**, off-world human economy.

IMPACTS

Social Impacts

Forges Lunar Tech to Save Lives on Earth.
Ignites the Next 'Apollo Generation' of Innovators.

Economical Impacts

Unlocks the Trillion-Dollar Lunar Economy.
Democratizes Space with Open-Source Robotics.

Scientific Impacts

Turns the Moon into a 24/7 Scientific Laboratory.
Pushes the Boundaries of Discovery by Exploring Where Humans Cannot.

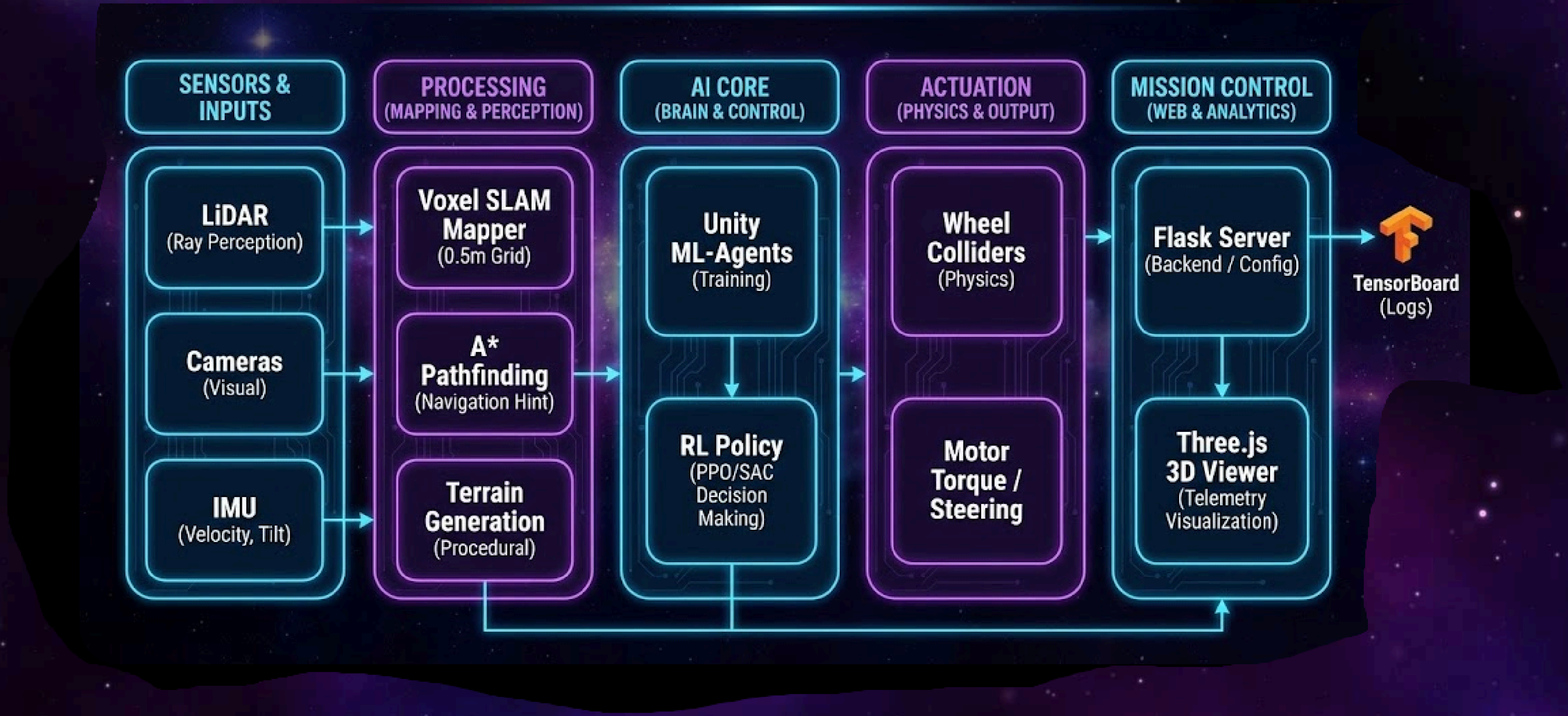
BENEFITS

Dramatically Reduces Mission Costs & Risk by replacing expensive, dangerous human EVAs with a reusable, autonomous workforce.

Maximizes Scientific Return on Investment (ROI) by automating routine tasks, freeing up valuable astronaut time for high-value research.

Enables Continuous & Hazardous Operations, allowing for 24/7 monitoring and exploration in areas considered too dangerous for humans.

Technical Approach



Research and References

Informationregarding the LunarSurface

- **Lunar Soil** - nih.gov
- **Lunar Electronics** - eeWorld
- **Gravity Effects** - FrontierSin Journals

Information regarding Navigation, Localization, and Mapping

- **SLAM Review -** nih.gov
- ROS- Automatic Addison
- SLAM Comparitive Study - Ancorasir

Information regarding AI wrt the project

- **Terrain Mapping using DeepLabV3+ -** Academia, UK
- **Applying RL in Dynamic Environments Detection using R-CNN** - Wipro
- **Unsupervised ML -** DCase Community

View our live demo here

YouTube Link

Information regarding Human-Robot Interaction

- **LLM Assistant** - PubMed Central
- **Multi Modal Interfaces -** NASA

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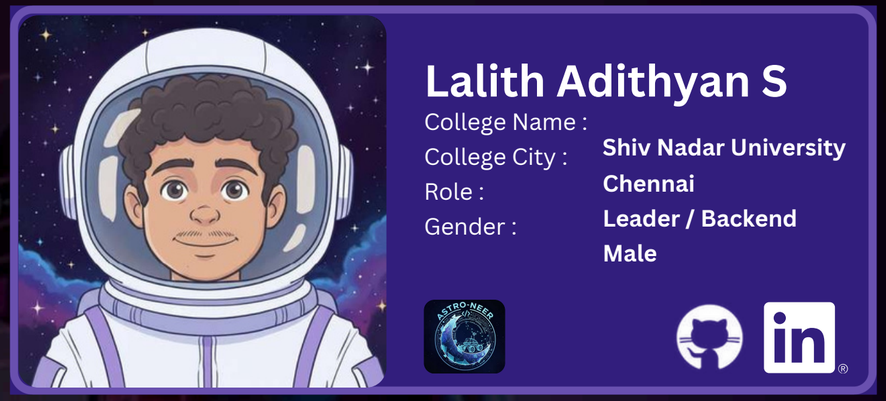
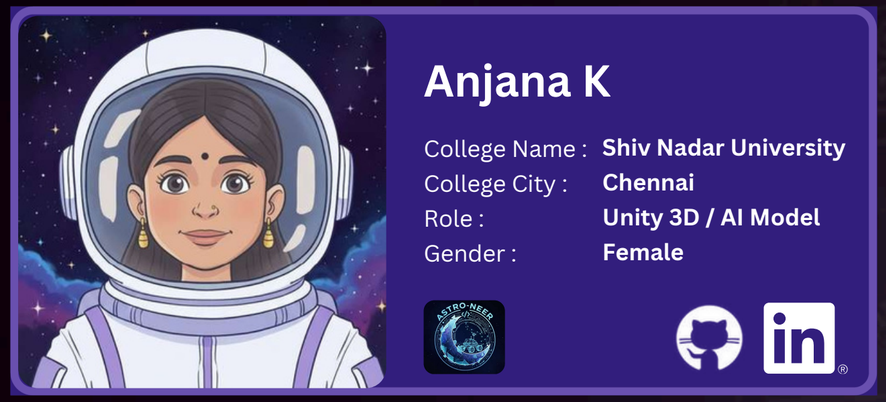
Team Name: ASTRO-NEER



Lalith Adithyan S

College Name : **Shiv Nadar University**
College City : **Chennai**
Role : **Leader / Backend**
Gender : **Male**



Anjana K

College Name : **Shiv Nadar University**
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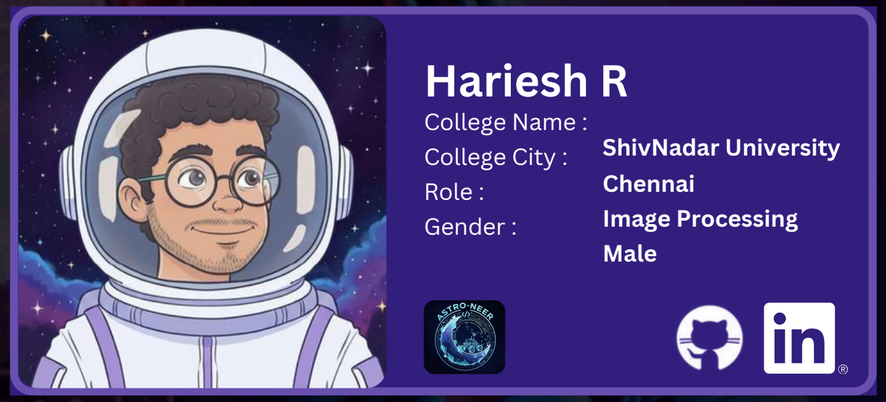
Role : **Unity 3D / AI Model**
Gender : **Female**



Hariesh R

College Name : **ShivNadar University**
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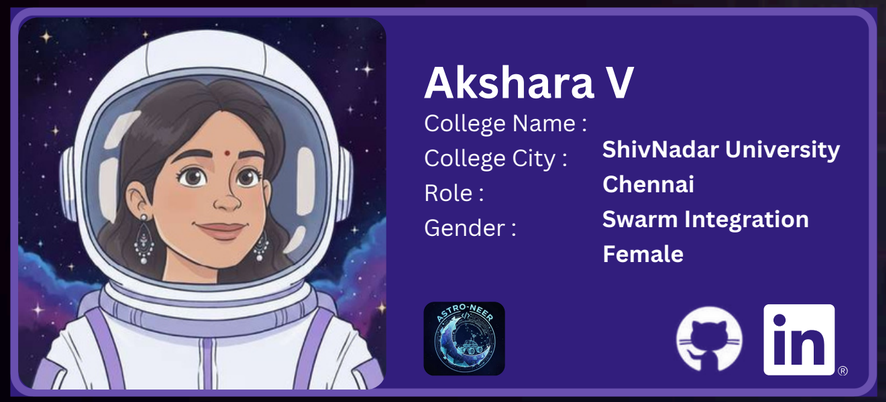
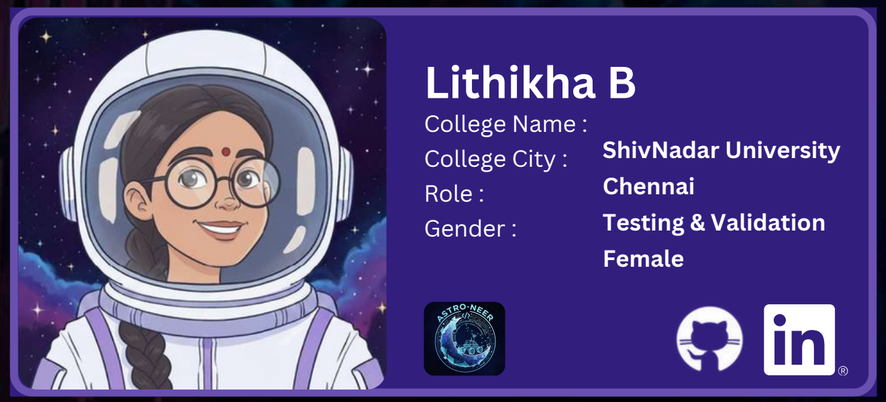
Role : **Image Processing**
Gender : **Male**



Akshara V

College Name : **ShivNadar University**
College City : **Chennai**
Role : **Swarm Integration**
Gender : **Female**



Lithikha B

College Name : **ShivNadar University**
College City : **Chennai**
Role : **Testing & Validation**
Gender : **Female**