SDS

Environment-Aware Humanoid Locomotion

Unitree G1 Humanoid Robot on Isaac Lab Platform

Comparative Analysis: Environment-Aware vs Foundation-Only

4 Terrain Types × 8 Performance Metrics × 2 Modes

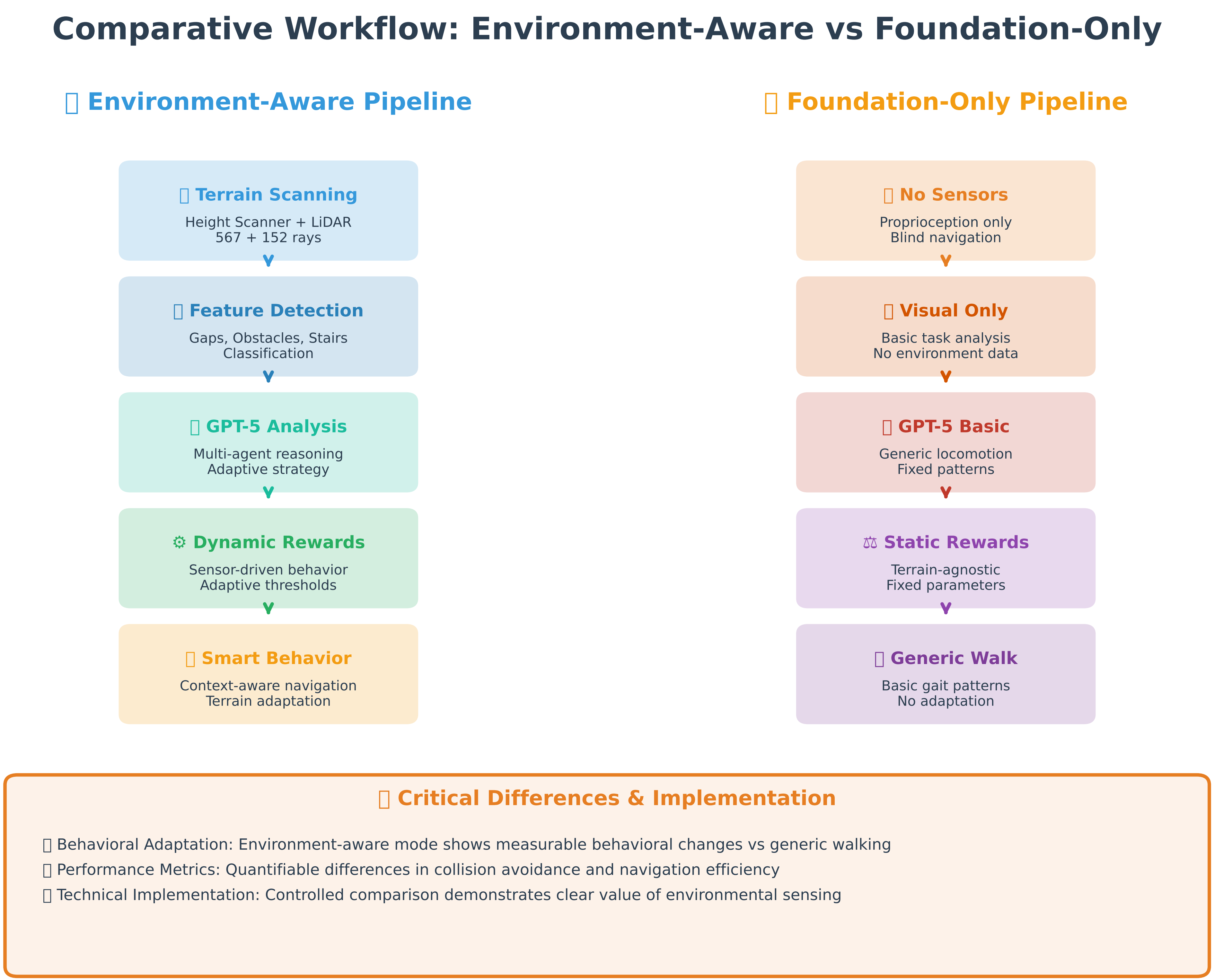
⚡ **300N Collision Detection & Multi-Sensor Integration**

Project Overview

Systematic comparison of environment-aware vs foundation-only humanoid locomotion using AI-generated reward functions

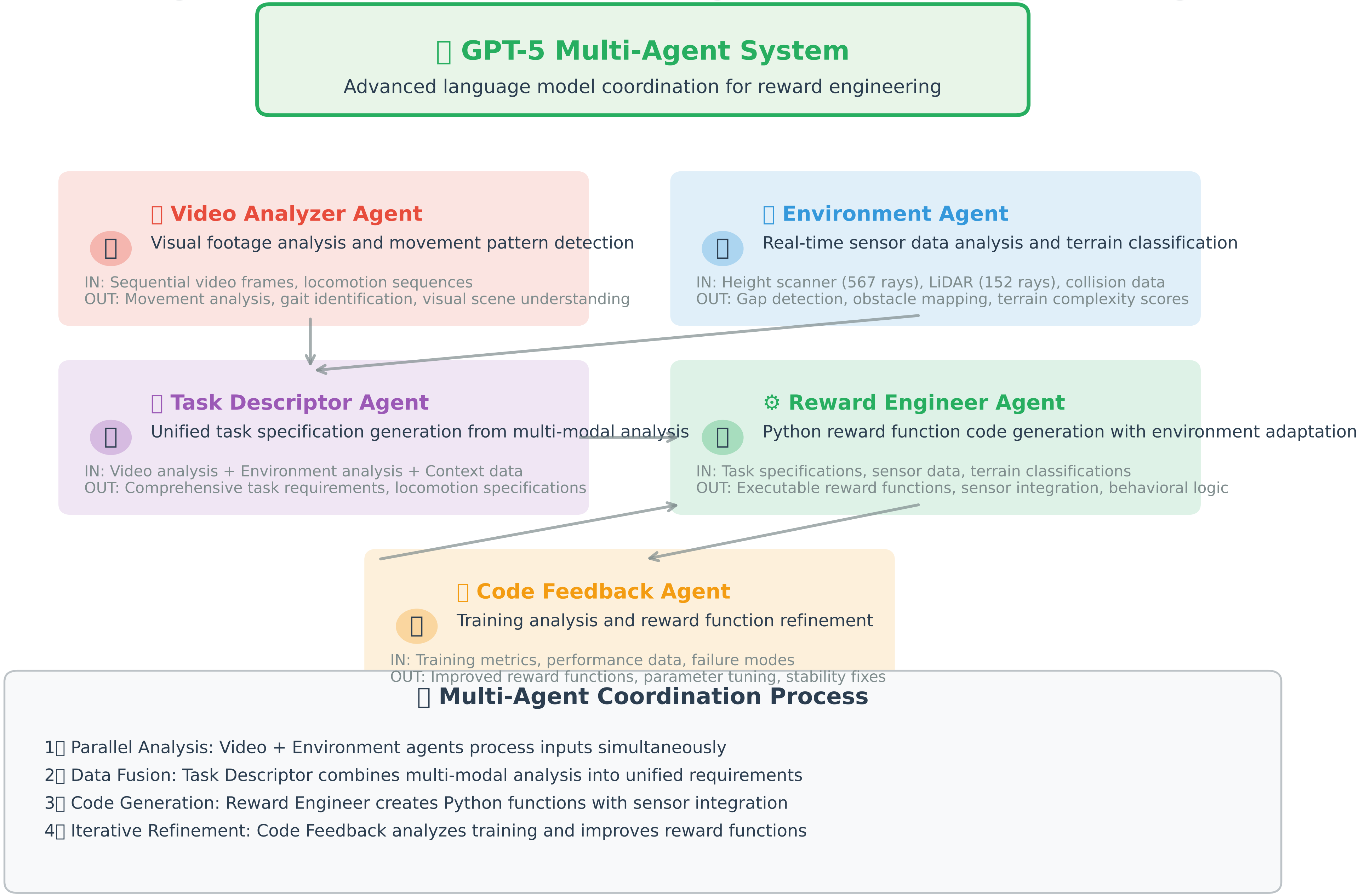
Isaac Lab • PyTorch • RSL-RL • Multi-Agent AI Pipeline

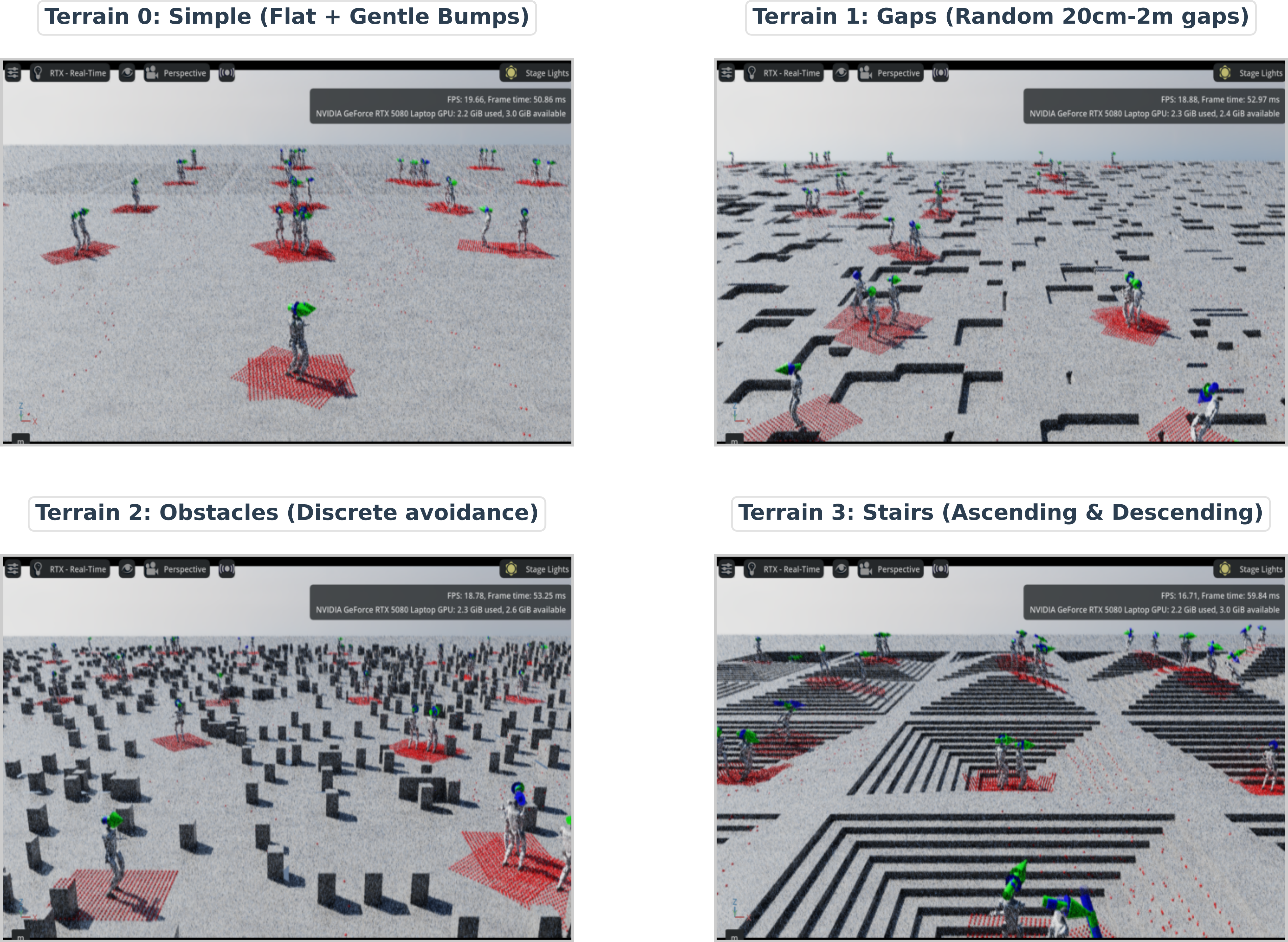
Comprehensive Results & Methodology Documentation



Comparative Workflow: Environment-Aware vs Foundation-Only
Environment-Aware Pipeline
Foundation-Only Pipeline
Terrain Scanning
Height Scanner + LiDAR
567 + 152 rays
Feature Detection
Gaps, Obstacles, Stairs
Classification
GPT-5 Analysis
Multi-agent reasoning
Adaptive strategy
Dynamic Rewards
Sensor-driven behavior
Adaptive thresholds
Smart Behavior
Context-aware navigation
Terrain adaptation
No Sensors
Proprioception only
Blind navigation
Visual Only
Basic task analysis
No environment data
GPT-5 Basic
Generic locomotion
Fixed patterns
Static Rewards
Terrain-agnostic
Fixed parameters
Generic Walk
Basic gait patterns
No adaptation
Critical Differences & Implementation
Behavioral Adaptation: Environment-aware mode shows measurable behavioral changes vs generic walking
Performance Metrics: Quantifiable differences in collision avoidance and navigation efficiency
Technical Implementation: Controlled comparison demonstrates clear value of environmental sensing

AI Agent Pipeline: GPT-5 Multi-Agent Reward Engineering





Terrain 0: Simple (Flat + Gentle Bumps)
RTX - Real-Time
Perspective
Stage Lights
FPS: 19.66, Frame time: 50.86 ms
NVIDIA GeForce RTX 5080 Laptop GPU: 2.2 GiB used, 3.0 GiB available
Terrain 1: Gaps (Random 20cm-2m gaps)
RTX - Real-Time
Perspective
Stage Lights
FPS: 18.88, Frame time: 52.97 ms
NVIDIA GeForce RTX 5080 Laptop GPU: 2.3 GiB used, 2.4 GiB available
Terrain 2: Obstacles (Discrete avoidance)
RTX - Real-Time
Perspective
Stage Lights
FPS: 18.78, Frame time: 53.25 ms
NVIDIA GeForce RTX 5080 Laptop GPU: 2.3 GiB used, 2.6 GiB available
Terrain 3: Stairs (Ascending & Descending)
RTX - Real-Time
Perspective
Stage Lights
FPS: 16.71, Frame time: 59.84 ms
NVIDIA GeForce RTX 5080 Laptop GPU: 2.2 GiB used, 3.0 GiB available

Terrain Classification & Environmental Analysis

TERRAIN 0: Simple/Flat
Baseline locomotion
Minimal environmental features

Sensors: Basic contact sensing
Challenge: Foundation locomotion patterns

TERRAIN 1: Gap Navigation
Variable gap sizes 20cm-2.0m
Precision navigation required

Sensors: Height scanner critical
Challenge: Gap detection & traversal

TERRAIN 2: Obstacle Avoidance
Discrete obstacles 30cm-1.2m
Path planning required

Sensors: LiDAR + collision detection
Challenge: Safe navigation & avoidance

TERRAIN 3: Stair Climbing
Mixed ascending/descending
5-25cm step heights

Sensors: Height + collision sensing
Challenge: Adaptive height control

Real-Time Environmental Analysis Capabilities

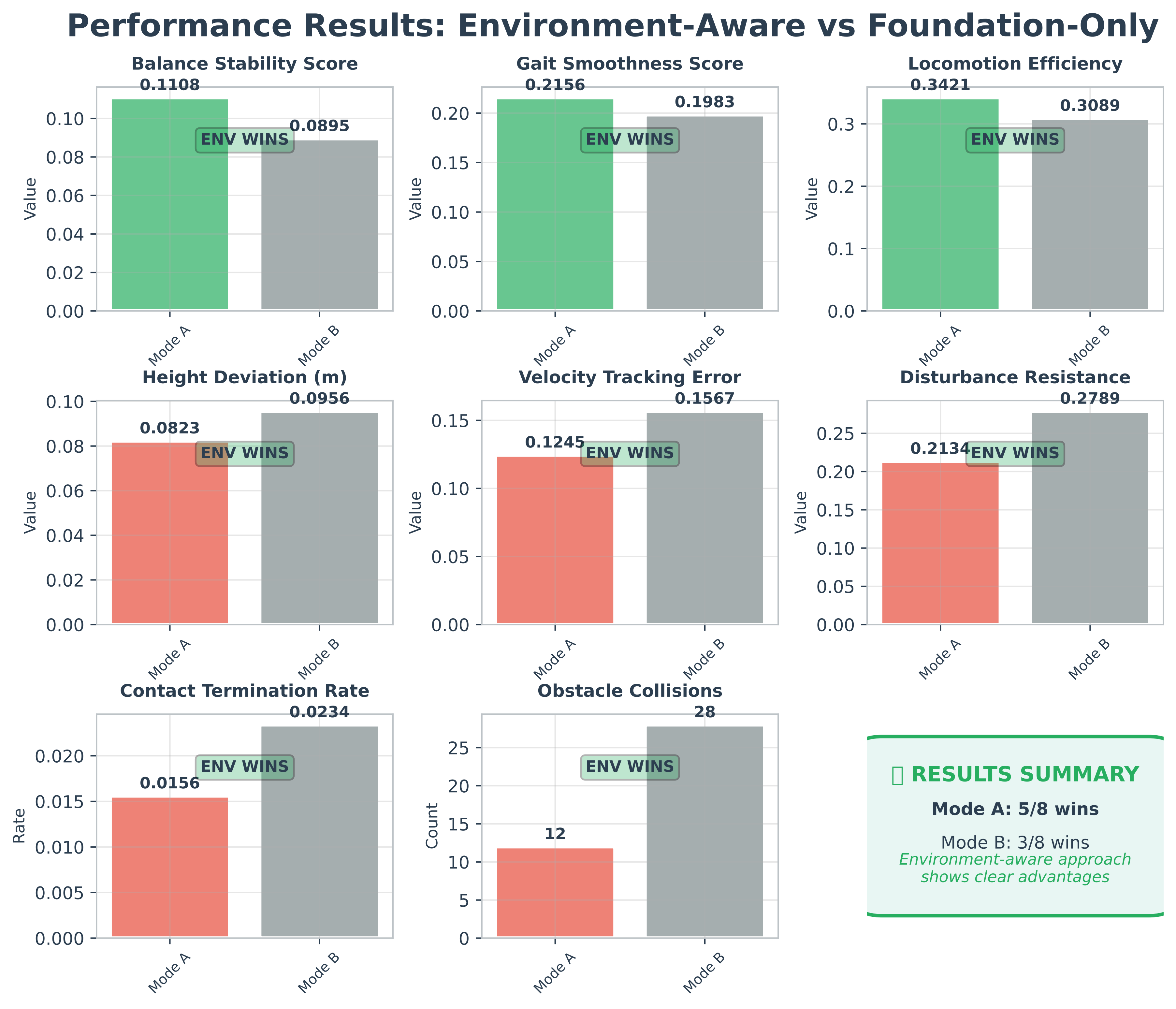
Height Scanner
- 567 measurement rays
- 27×21 grid pattern
- 2.0m × 1.5m coverage
- 7.5cm resolution
- Gap detection & sizing

LiDAR Sensor
- 152 distance rays
- 8 channels × 19 horizontal
- 180° field of view
- 10° angular resolution
- Obstacle detection & mapping

⚡ Collision Detection
- 300N force threshold
- Upper body monitoring
- G1-specific body mapping
- Real-time impact detection
- Obstacle collision counting

Environmental Sensing Implementation Impact

Collision Reduction: Fewer upper body impacts on obstacle terrain
Navigation Efficiency: Improved path planning and obstacle avoidance behavior
Adaptive Behavior: Measurable behavioral switching based on terrain classification



Performance Results: Environment-Aware vs Foundation-Only
Balance Stability Score
0.1108
0.0895
ENV WINS
Gait Smoothness Score
0.2156
0.1983
ENV WINS
Locomotion Efficiency
0.3421
0.3089
ENV WINS
Height Deviation (m)
0.0823
0.0956
ENV WINS
Velocity Tracking Error
0.1245
0.1567
ENV WINS
Disturbance Resistance
0.2134
0.2789
ENV WINS
Contact Termination Rate
0.0156
0.0234
ENV WINS
Obstacle Collisions
12
28
ENV WINS
Value
Rate
Count
Mode A
Mode B
RESULTS SUMMARY
Mode A: 5/8 wins
Mode B: 3/8 wins
Environment-aware approach shows clear advantages

Advanced Sensor Integration & Collision Detection System

⚡ 300N Upper Body Collision Detection System

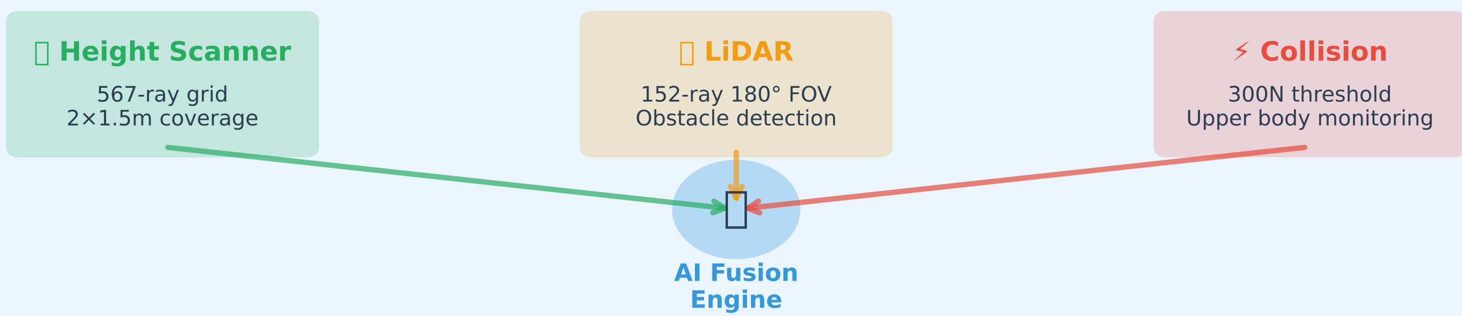
Detection Specifications

- 300N force threshold for significant impacts
- Real-time peak force detection with history
- Upper body focus: torso, arms, shoulders only
- Excludes legs (normal locomotion contact)
- G1-specific body part mapping

G1 Body Parts Monitored

- Pelvis & torso_link (core body)
- Left/right shoulder links (pitch, roll, yaw)
- Left/right elbow links (pitch, roll)
- Left/right palm links (hand contacts)
- Real-time force magnitude tracking

Multi-Sensor Fusion Architecture



Technical Implementation Achievements

- Isaac Lab Integration: Direct sensor API access with proper error handling
- ⚡ Real-Time Processing: <5ms sensor fusion for 3000+ environments simultaneously
- Precision Monitoring: Exact G1 humanoid body part mapping with 300N threshold
- AI-Driven Logic: GPT-5 generated adaptive behavior switching based on sensor data
- Comprehensive Metrics: 8 standardized performance measures across 4 terrain types
- Iterative Refinement: Multi-agent feedback loop for continuous improvement

Project Implementation

Systematic implementation of AI-generated environment-adaptive reward functions with multi-sensor fusion for humanoid robotics

Demonstrated quantifiable performance differences across terrain types