

Scalable Urban Simulation for Generalizable Micromobility Robot Learning

Appendix

I. URBAN-BENCH: A SUITE OF ESSENTIAL TASKS FOR AUTONOMOUS MICROMOBILITY


In this section, we introduce URBAN-BENCH, a suite of essential tasks and benchmarks that capture high-frequency scenarios in autonomous micromobility. Based on the data from users of micromobility, we first summarize several key **Human Needs** (Section I-A) as the basis of the task definition. The real-world demands for micromobility devices mainly ask for two primary skills: **Urban Locomotion** (Section I-B) — moving stably across diverse terrains, including flat, slope, stair, and rough surfaces, and **Urban Navigation** (Section I-C) — moving efficiently in spaces with varying conditions like unobstructed pathways, static, and dynamic obstacles. Furthermore, we define a long-horizon task, **Urban Traverse** (Section I-D), where robots must navigate urban spaces at kilometer scales. To tackle this challenging task, we introduce a pilot approach - human-AI shared autonomy - leveraging the power of both humans and AI agents.

A. Tasks Grounded in Human Needs


The selection of tasks in URBAN-BENCH is informed by urban mobility studies and infrastructure assessments, highlighting their practical importance. U.S. Department of Transportation (DOT) reports [1] indicate the prevalence of diverse terrains like ramps, stairs, and uneven surfaces in public spaces, so it is necessary to have various locomotion capabilities, including *slope traversal*, *stair climbing*, and *rough terrain traversal*. Besides, the National Household Travel Survey (NHTS) [2] indicates that a significant portion of urban travel involves short trips on sidewalks and plazas, where micromobility devices must navigate both unobstructed pathways and crowded zones. This underscores the need for safe and efficient *clear pathway traversal*, and *static* and *dynamic obstacle avoidance*. Based on these scene conditions, we define a set of essential tasks of urban locomotion and navigation.


B. Urban Locomotion


In urban locomotion, the embodied AI agent controls the robot's locomotion, ensuring stable and efficient movement across various terrains such as flat surfaces, slopes, and stairs. We define four tasks for urban locomotion (Figure 1 (a)) based on different ground conditions as below:

 **LocoFlat** → **Flat Terrain Traversal**: Traversing stable, flat surfaces commonly found on sidewalks and pedestrian

zones. This is necessary for basic mobility in city spaces designed for foot traffic.


 **LocoSlope** → **Incline Ascent and Descent**: Moving up and down ramps and inclined surfaces with varying slope angles. This is essential in urban areas where slopes and accessibility ramps are common.


 **LocoStair** → **Stair Ascent and Descent**: Ascending and descending stairs with varying heights. This is critical in urban spaces where ramps are unavailable, allowing access to multi-level areas.


 **LocoRough** → **Uneven Terrain Traversal**: Maintaining stability on uneven surfaces like cobblestones or damaged sidewalks. This is important for robust movement in urban environments with irregular, worn-down paths.

C. Urban Navigation

In urban navigation, the embodied AI agent handles local navigation, determining how the robot should move to stay within traversable areas while avoiding obstacles and pedestrians. We define three tasks for urban navigation (Figure 1 (b)) based on different scene conditions as below:


 **NavClear** → **Traversable Area Finding**: Moving across open, unobstructed ground, avoiding non-walkable areas like mud or bushes. This is essential for efficient navigation on open plazas and trails on lawns.

 **NavStatic** → **Static Obstacle Avoidance**: Navigating around stationary urban obstacles such as benches, trash bins, and signposts. This is vital for safely maneuvering in crowded city environments with fixed structures.

 **NavDynamic** → **Dynamic Obstacle Avoidance**: Adjusting paths to avoid moving obstacles like pedestrians and cyclists. This is crucial in urban spaces with high foot traffic, ensuring safe interactions with moving entities.

D. Urban Traverse

In kilometer-scale urban traverse, the embodied AI agent's goal is to reach the target point as efficiently as possible, minimizing travel time while ensuring safety in the journey. We define the urban traverse task (Figure 1 (c)) as below:

 **TRA** **Traverse** → **Urban Traverse**: Moving from point A to point B with a distance of more than 1 *km* within a complex urban environment safely and efficiently. A challenging real-world setting for micromobility.

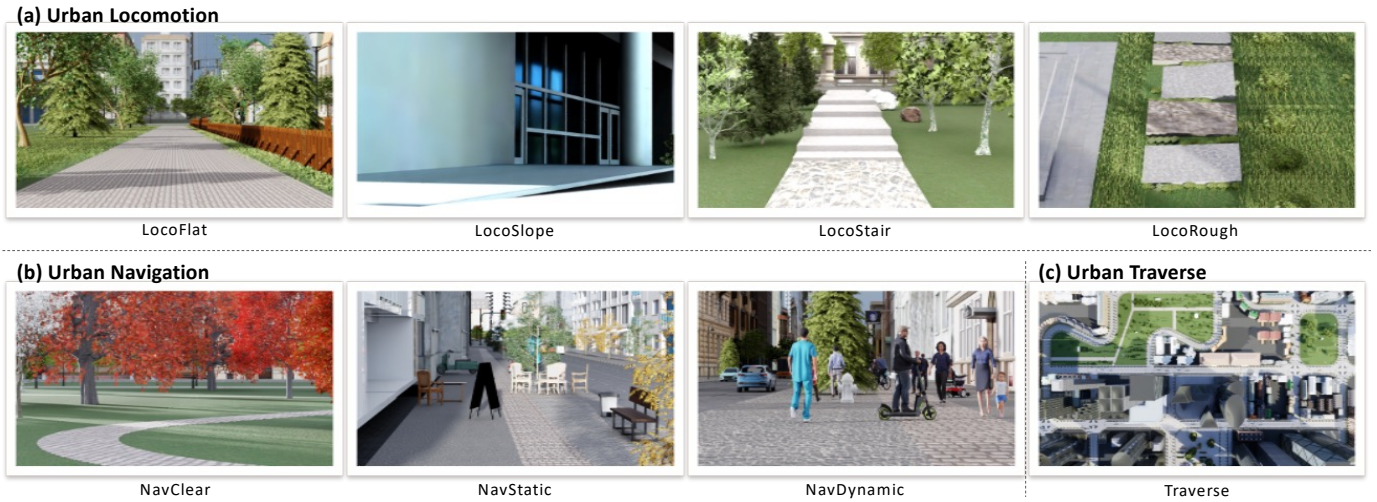


Fig. 1: **URBAN-BENCH: a suite of essential tasks for autonomous micromobility.** Simulation environments of eight essential tasks of (a) Urban Locomotion, (b) Urban Navigation, and (c) Urban Traverse.

a) Human-AI shared autonomous approach.: We propose a human-AI shared autonomous approach as a pilot study to address this task, combining AI capabilities with human interventions. In this approach, we structure the robot control into three layers: high-level decision-making, mid-level navigation, and low-level locomotion. With the layered architecture, we decompose the complex urban traverse task into a series of subtasks, with AI managing mid-level and low-level routine tasks, and humans making high-level decisions and intervening in risky situations. This approach allows a flexible transition between human and AI control. Humans can manage the entire process if needed, while AI can manage the entire operation using an extra rule-based/AI-based decision model to direct the dispatch of urban navigation and locomotion models.

REFERENCES

- [1] U.S. Department of Transportation. Transportation reports and publications. <https://www.transportation.gov/>, 2024. Accessed: 2024-11. 1
- [2] U.S. Federal Highway Administration. National household travel survey (nhts). <https://nhts.ornl.gov/>, 2017. Accessed: 2024-11. 1