# Navigation in Dynamic Workspaces: Integrated Task and Motion Planning for Bipedal Locomotion

Abdulaziz Shamsah*, Jonas Warnke*, Zhaoyuan Gu, and Ye Zhao
*Laboratory for Intelligent Decision and Autonomous Robots*
*Woodruff School of Mechanical Engineering, Georgia Tech, Atlanta, GA, USA*
*equally contributed, ({ashamsah3, jwarnke, zgu78}@gatech.edu, ye.zhao@me.gatech.edu)

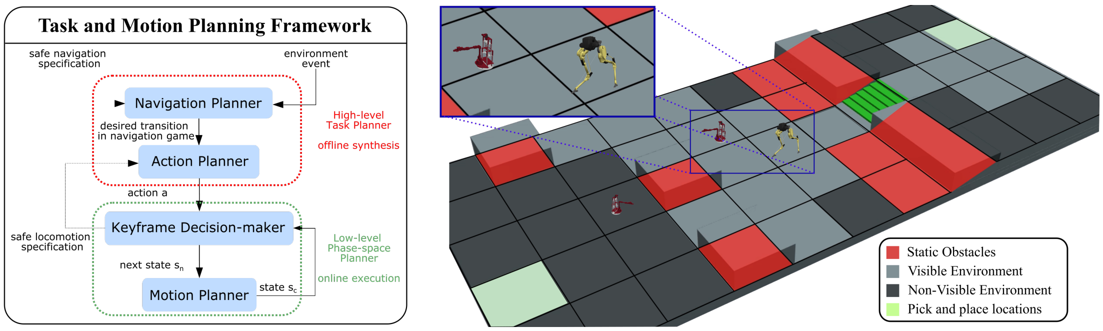


**Figure 1:** Proposed hierarchical planning framework and bipedal navigation in a partially observable environment with dynamic obstacles.

## I. Motivation

As robots become ubiquitous in real-life workspaces, reasoning about mobility safety at both task and motion planning levels is imperative. Navigation safety and obstacle avoidance in mobile robots [1], as well as balancing safety in legged locomotion [2], have been widely explored in the locomotion literature. However, the field lacks literature exploring safety from both levels for legged locomotion, due to the inherent challenge of guaranteeing safe execution of high-level commands in hybrid and underactuated systems such as bipedal robots. To this end, we have proposed a hierarchical planning framework that integrates safety for the high-level task planner and low-level motion planner cohesively by encoding the low-level dynamics into the high-level task specification design [3]. To account for real world scenarios, the robot operates in a partially observable environment, where it can only locate dynamic obstacle within a local visible range. In this work, we target locomotion planning for a Cassie bipedal robot in the presence of uneven terrain and dynamic obstacles with multi-level safety guarantees.

## II. Method

We design a coherent hierarchically planning structure using a combined *top-down* and *bottom-up* approach depicted in Fig. 1. We synthesize a high-level task planner, consisting of navigation and action planners, *offline* by constructing a two-player game between the robot and its possibly adversarial environment that is governed by temporal-logic specifications. The navigation planner uses a belief abstraction to reason about the possible locations of out-of-sight dynamic obstacles to generate a safe navigation strategy, while the action planner generates feasible actions at each locomotion step that guarantee the desired walking step transitions in the navigation game. A keyframe decision-maker then chooses viable keyframe states *online* through a sampling-based optimization, namely apex velocities that guarantee balancing safety and lateral tracking of high-level waypoints. At the low level, a phase-space motion planner generates locomotion trajectories using the keyframe states from a reduced-order model. Properties of the low-level safe keyframe policy are incorporated into the high-level specification design to guarantee that only safe actions are chosen. A nonlinear program based gait library is then implemented to generate optimal whole-body trajectories for Cassie. We evaluate the performance of the proposed framework by synthesizing a navigation plan for a package delivery task in a partially observable environment with dynamic obstacles (see Fig. 1). In the proposed framework, the robot *actively* avoids collisions with dynamic obstacles by either steering away or coming to a stop.

## III. Ongoing Works

Our current work focuses on the following: (i) online integration between the high-level task planner and the low-level motion planner to allow for task-level re-planning. (ii) Recoverability capture basin computation in the phase-space planning layer to design robust trajectories in the presence of environmental perturbations. (iii) Joint belief abstraction for multiple dynamic obstacles without significant computational cost increase.

## References

[1] H. Kress-Gazit, M. Lahijanian, and V. Raman, "Synthesis for robots: Guarantees and feedback for robot behavior," *Annual Review of Control, Robotics, and Autonomous Systems*, 2018.

[2] T. Koolen, T. De Boer, J. Rebula, A. Goswami, and J. Pratt, "Capturability-based analysis and control of legged locomotion, part 1: Theory and application to three simple gait models," *The international journal of robotics research*, vol. 31, no. 9, pp. 1094–1113, 2012.

[3] J. Warnke, A. Shamsah, Y. Li, and Y. Zhao, "Towards safe locomotion navigation in partially observable environments with uneven terrain," in *IEEE Conference on Decision and Control*. IEEE, 2020, pp. 958–965.