In the age of robots coexisting with humans, enhancing their ability to perceive and engage with the world is paramount in terms of safety and efficiency. Just as human drivers use mirrors and check blind spots for better situational awareness, a robot's active perception system must continuously gather crucial scene information to interpret and interact more precisely [1]. **My research is centered on harnessing this proactive awareness to enable robust robot interactions, especially in dynamic environments where they operate alongside people.** One specific area of interest is fast-paced construction sites, where robots need to scan and map locations without disrupting ongoing work. These challenges involve: (*i*) perceptual intelligence in highly dynamic scenes; (*ii*) safe and efficient robot task execution in human-operated spaces; and (*iii*) coordinating among various robots and robot-human tasks.

Foundational prior work: Driven by the guidance and mentorship of Prof. Sebastian Scherer, Prof. Jiaoyang Li, and Dr. Micah Corah, my work is at the intersection of **active perception, safe task and motion planning, and multi-agent systems**.

At CMU, I've contributed to the collaborative "multi-drone reconstruction" project, addressing a significant data gathering gap. Our research develops methods for accurately measuring large-scale dynamic group activities of people and animals in the wild. The project empowers a team of UAVs to detect, track, predict, follow, coordinate, and reconstruct such group behavior. Within the domain of safe multi-robot coordination, I've focused on path planning for multiple robots to ensure human safety, avoiding collisions with drones, the environment, and moving actors.

In addition to conducting field tests, I addressed the challenge of multiple robots completing tasks by proposing a **multi-task optimization method**. Collaborating with my CMU class instructor Prof. Li, I developed a framework to encourage task-sharing among robots, minimizing total path costs without explicit task assignments and leveraging the homogeneity of the multi-robot system. As the first author, my unique contribution to such problem setting was presented at the **IROS 2023 Workshop** [2], challenging the conventional one-robot-one-task approach.

In my work on **active perception**, I enhance the multi-robot data-acquisition framework by focusing on scene views. To gauge the low-level geometric attributes of the mesh world representation, I delve into pixel-level metrics, specifically Pixel-Per-Area (PPA). To ensure comprehensive coverage, I devise this as a submodular function, maximizing PPA through sequential Markov Decision Process (MDP) solutions for each robot by providing diminishing rewards for already observed pixels. This approach significantly boosts perceptual awareness, **outperforming the state-of-the-art formation-based baseline by up to 25%**. It's currently under review for **ICRA 2024** [3], with a short version presented at the **IROS 2023 Workshop**.

In my research involving **perceptually aware multi-robot systems** navigating obstacle-filled environments, I encountered significant challenges. These included addressing ego-centric behaviors among robots, handling complex deployment factors like robot dynamics, and ensuring efficient single-robot long-term perceptual planning while maintaining human safety. To overcome these challenges, I engaged in insightful discussions with Prof. Likhachev and leveraged insights from my IROS paper [2]. I introduced a novel PPA-driven conflict-resolution approach to coordinate robots, achieving performance levels similar to scenarios without inter-robot constraints. This innovative heuristic relies on a preference-based multi-objective formulation and is supported by a lower-level single-robot view search method that has proven to be up to **72 times more time-efficient** than the traditional value-iteration method involving MDP model creation. As the lead author, I'm currently preparing this research for IEEE RA-L submission [4].

Current work: A limitation of my prior work was the perception system's inability to learn from past experiences for improved scene representation, limiting adaptability in stochastic settings. In collaboration with Prof. Katia Sycara, I'm also pursuing relevant coursework on "Visual Learning R." in Fall 2023, focusing on active vision systems. I'm exploring the use of **uncertainty-aware models and planners to guide robot operations**. This approach enables a diversely trained model to perform view synthesis and compute uncertainty at novel locations based on recent observations, and it recently received the "best project award" for my presentation of a cut-scene augmentation method for training on larger outdoor scenes. An intriguing future direction involves leveraging scene semantics, such as the correlation between doors and rooms, to enhance uncertainty model accuracy and assist robots in developing better strategies.

Future research direction: With these experiences, I've realized that a robot's ability to interact robustly hinges significantly on its perception stack. However, most of the robot's experiences are learned in simulators and require uncertainty estimates that adapt to Sim2Real transfer. Recent breakthroughs with dynamic 3D Gaussians [5] in scene representation promise close alignment with ground truth, leveraging GPU acceleration and rasterization for real-time applications. **In my PhD, I aim to focus on:** (*i*) Introducing uncertainty estimation in such representation in multi-agent robot perception, learning, and planning within dynamic human-involved environments; (*ii*) Investigating exploration heuristics guided by these metrics to optimize search processes, addressing challenges from [4]; (*iii*) Exploring visual cues for adaptive weights in the multi-agent system's multi-objective function for negotiation in state and action space.

Over the years, my diverse experiences have shaped my publication approach, focusing on delivering high-quality work and meaningful results. Traits like patience and perseverance, honed during my undergraduate years debugging complex robotic systems [6, 7], have bolstered my research efforts, even in challenging situations. My industry background has not only improved my engineering skills but also cultivated a practical mindset, emphasizing timely execution and scalable solution creation. Additionally, I've had the privilege of mentoring students, providing lessons on Kalman filtering to develop custom filtering based on my field experiences, and actively guiding students in their first drone flights at the Airlab. I aim to continue fostering this spirit throughout my Ph.D.

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