Generative AI for the Physical World

The advent of robotics promises to transform everyday life by automating mundane tasks, thus freeing humans to engage more deeply with their creative and intellectual pursuits. These systems are found in applications such as household robots, autonomous vehicles, and smart infrastructure. As advances in computing and manufacturing expand the capabilities of these systems, there is a growing need for design tools that can navigate the complex possibilities these advancements present. Current engineering approaches are time-intensive and heavily rely on human input for prototyping and iteration. This difficulty is further compounded by the vast robot design space that one needs to explore.

Our research proposal addresses some of these challenges by focusing on the development of design tools for robots that integrate physical form and virtual cognition. In this work, we propose an approach that is data-driven, generative and modular. This approach not only streamlines the design process but also enhances design efficiency which can potentially reduce the complexity and costs of robot production.

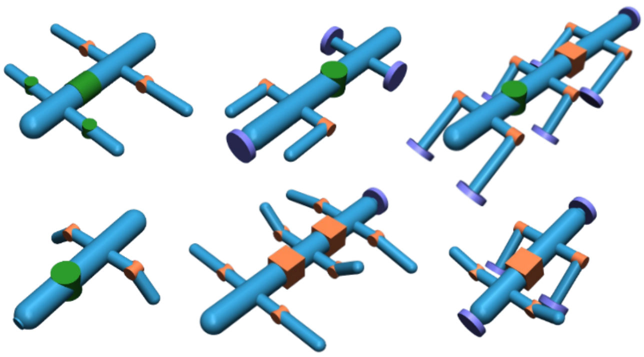

Figure 1: Computational robot designs generated by LLM.

AI-powered computational design tools. By ensuring accessibility for users with varying levels of expertise, AI-powered design tools will enhance human creativity and boost design performance. By leveraging tools such as LLMs, we can automate the generation of robot designs based on natural language commands, significantly speeding up exploration of the design space as shown in Figure 1. To ensure practical and implementable designs, we will employ prompt engineering techniques, including providing task descriptions and constraints depicted in graph structures. This approach will enhance the diversity and feasibility of generated designs, marking a significant departure from traditional manual design methods.

Digital twin of the robot model. Design is iterative, with key bottlenecks being the number and duration of iterations. Digital twins, which are fast, accurate, and informative, can significantly accelerate this process. To bridge the gap between simulation and reality, we propose adapting simulators to new domains using sparse experimental data. Coarse simulators will provide physical priors refined by data-driven models, which, combined with differentiable simulators, will apply corrective forces to capture discrepancies.

Co-optimization of brain and body. Developing robots that mirror the co-evolution of the brain and body, inspired by natural systems, is essential for effective interaction with complex environments. This approach will result in robots with human-like adaptability, capable of performing a wide range of tasks in dynamic settings.

Robots collaborating with robots. Developing robots that can autonomously construct other robots in collaborative real-world settings will lead to multi-robot systems to perform complex tasks beyond the capabilities of individual robots. This involves using a bimanual manipulation system with two robot arms equipped with sensors for precise handling and collision avoidance. The system employs imitation learning, where robots learn the assembly process by observing expert demonstrations.

Biomimetics and biological intelligence. Studying nature-inspired strategies will guide the design of robotic systems capable of autonomous learning and adaptation in dynamic environments. By incorporating biomimetic and biologically inspired methods, we aim to develop intelligent robots that can navigate and function in diverse, unpredictable contexts. Learning from evolutionary processes and biological principles will advance intelligent behavior in robots, leading to more advanced and robust systems.