RobotSketch: An Interactive Showcase of Superfast Design of Legged Robots

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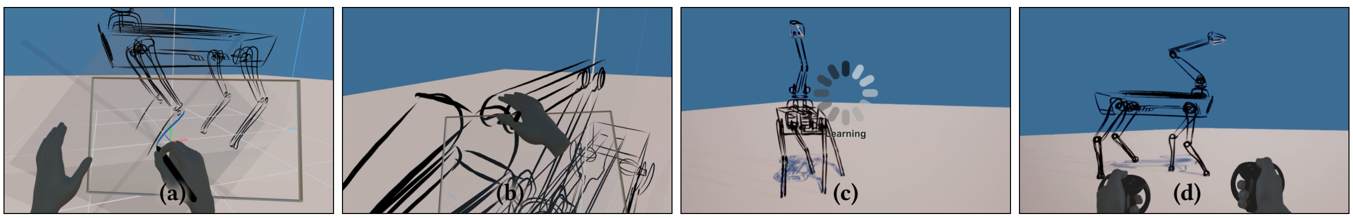

Figure 1: We showcase a novel interactive system where a robot designer can (a) directly sketch a robot in 3D using a transparent panel synchronized with a physical graphics tablet, and (b) experience the result at real scale within an immersive VR workspace. (c) The concept robot acquires walking skills through reinforcement learning in a physics simulation, (d) allowing the designer to control it in real time using VR controllers.

ABSTRACT

Robots consisting of many articulated parts performing complex movements are challenging to design. We showcase an interactive system for exploring shapes and structures of robots through 3D sketching, generating plausible movements of robots through AI, and reviewing and refining them in VR. Such immersive prototyping in the early stages can help reduce the time and cost associated with trial and error in later stages, contributing to shortening and streamlining of the robot development process.

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1 INTRODUCTION

With rapid advancements in cutting-edge robotics, we are entering a new era of robots that exhibit organic forms and functions, such as Spot from Boston Dynamics and Digit from Agility Robotics. Equipped with powerful onboard AI, these robots are expected to offer valuable services to people, and may adopt shapes and structures specialized for environments and circumstances in which they operate. These trends point to an imminent Cambrian explosion in the robotics ecosystem.

However, the current robot development process requires months or even years of design and engineering before it is possible to validate a robot's ability to perform desired movements, at which point failure necessitates returning to the drawing board. This lengthy development cycle is a severe bottleneck that needs to be addressed for the robotics industry to meet the rapidly diversifying and evolving demands for commercial robots.

Our novel interactive system combines 3D sketching, VR, and AI to facilitate a new design workflow for the early stages of robot development (Figure 1). Robot designers can quickly express robots' 3D shapes and structures and experience them at real scale by creating 3D sketches in an immersive VR workspace. The resulting concept robots can acquire legged locomotion skills that comply with the laws of physics through reinforcement learning and walk fluently in response to designers' instructions. Reviewing these results in real time can help designers iterate on the robot design in shorter cycles.

2 RELATED WORK

Pen-based 3D sketching: In the early stages of product design, industrial designers perform 2D perspective sketching to quickly and effectively ideate 3D forms and functions of new products. These sketches contain abundant 3D information that can be leveraged for intuitively authoring 3D models consisting of 3D curves [Bae et al. 2008]. Recently, a novel system for 3D sketching of complex kinematic structures was introduced [Lee et al. 2022]. We extend this system for sketching robots.

Transparent panel-based interaction in VR: 3D sketches can be visualized in VR at real scale [Drey et al. 2020] without requiring any time-consuming CAD modeling or 3D printing. In our system, 3D sketching on a graphics tablet with a stylus in VR emulates the natural experience of drawing on a glass window against a backdrop of scenery. We eliminate binocular parallax, which causes objects to appear duplicated and overlapping in such a setup, by applying monoscopic flattening [Lee et al. 2023].

Reinforcement learning-based AI for walking: A control method based on reinforcement learning was developed [Hwangbo et al. 2019], where robots in a physics simulation [Hwangbo et al. 2018], driven by neural networks, find appropriate control policies for legged locomotion through trial and error. This method enables control of robots with novel configurations in a short time, so it is ideal for early-stage robot design, where robot designers need to explore as many options as possible.

3 SYSTEM & IMPLEMENTATION

In our system, a robot designer can express the 3D shapes and structures of robots with complex kinematic structures by performing pen and multi-touch gestures on a graphics tablet [Lee et al. 2022] in VR (Figure 1a). Additionally, they can annotate necessary physical properties and metadata on the sketch.

Similar to a glass window, a transparent tablet allows the designer to perceive the 3D sketch behind it in stereoscopic depth (Figure 1b), but when the hands approach the tablet to interact, the sketch is monoscopically flattened (Figure 1a), enabling precise interaction without binocular parallax [Lee et al. 2023].

The neural networks of the completed concept robots, based on the GRU-MLP architecture [Youm et al. 2024], are trained to fluently walk through reinforcement learning using proximal policy optimization [Schulman et al. 2017] in the RaiSim physics simulation [Hwangbo et al. 2018] running on the server (Figure 1c).

After the training, in the VR client, the designer can manipulate the translation and rotation of the concept robots in real time using the two thumbsticks of VR controllers (Figure 1d).

Our system's client was implemented using the Unity 3D engine, a Wacom Cintiq Pro 24 Touch graphics tablet, and a Meta Quest 3 VR headset. Through TCP sockets, the client sent sketches and movement instructions from the designer, and the server sent back the robots' real-time poses.

4 INTERACTIVE SHOWCASE

In our interactive showcase, a robot designer 3D sketches bipedal, tripedal, quadrupedal, or even hexapedal walking robots in VR (Figure 2). Attendees view these life-sized robots, from inside or outside of VR, learning to walk in a physically plausible manner through trial and error, moving freely as instructed by the designer.

5 CONCLUSION

We present a novel, futuristic robot design workflow that combines the strengths of 3D sketching, VR, and AI. In doing so, we highlight the growing importance of sketching in a newly emerging mode of accelerated creativity and productivity, where human designers focus on expressing the core ideas and then AI-based techniques fill in the gaps. This approach enables more informed design decisions to be made earlier in the development process, which may present critical advantages in cutting-edge industries such as robotics.

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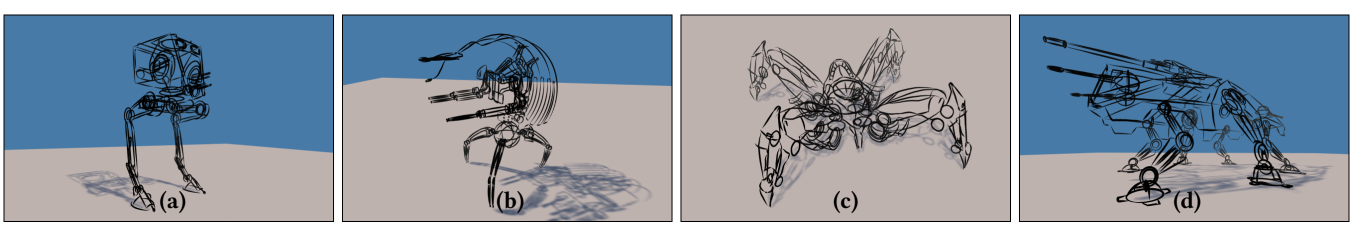

Figure 2: Our system can train even atypically structured robots such as (a) the bipedal AT-ST, (b) the tripedal Droideka, (c) the quadrupedal Dragoon, and (d) the hexapedal AT-TE from *Star Wars* and *StarCraft* to walk in a physically plausible manner.