JetController: High-speed Ungrounded 3-DoF Force Feedback Controllers using Air Propulsion Jets

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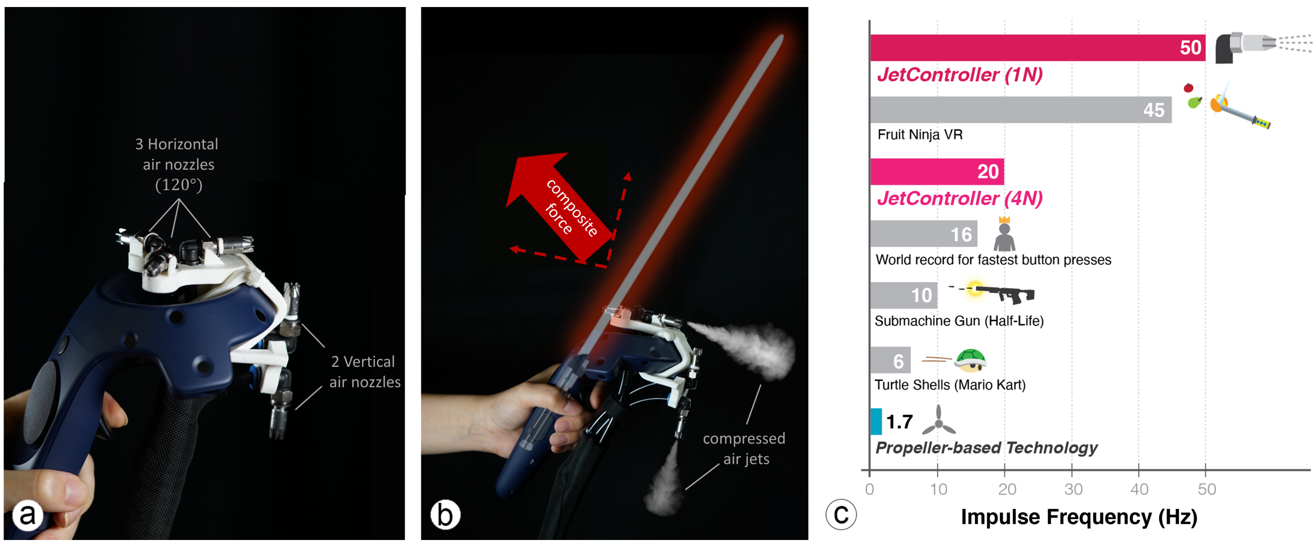

Figure 1: (a) JetController design for the HTC Vive VR controller, (b) provides ungrounded 3-DoF force feedback by modulating compressed air jets, and (c) high-speed 3-DoF force feedback achieving impulse frequency of 20Hz at 4.0N and 50Hz at 1.0N to support popular game events. (note: the white smoke is only shown for illustrative purposes.)

ABSTRACT

JetController is a novel high-speed, persistent 3-DoF ungrounded force feedback controller. It uses high-speed pneumatic solenoid valves to modulate compressed air to achieve full impulses of 50Hz at 1.0N (20Hz at 4.0N), and combines multiple air propulsion jets to generate 3-DoF ungrounded force feedback. Compared to propeller-based approaches, JetController supports 10-30 times faster impulse frequency, and its handheld device is significantly lighter and more compact. JetController enables a wide range of haptic events in games and VR experiences, from firing automatic weapons in games like Halo (15Hz) to slicing fruits in Fruit Ninja in 3-DoF (up to 45Hz). To demonstrate JetController, we integrated our prototype with two best-selling VR games, Half-life: Alyx and Fruit Ninja VR, to highlight a variety of 3-DoF interactions that were not possible before.

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CCS CONCEPTS

• **Human-centered computing → Haptic devices**.

KEYWORDS

High-speed haptic feedback, air propulsion, ungrounded force

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1 INTRODUCTION

Haptic feedback enhances virtual experiences. Many types of haptic feedback are provided 1:1 to user input, such as throwing turtle shells in Mario Kart; while some are many-to-one, such as firing automatic weapons in Halo and Half-Life (10-15Hz), and slicing multiple fruits in Fruit Ninja (up to 45Hz) with a single swing.

3-DoF force feedback devices have been developed to significantly improve haptic feedback fidelity. To allow users to freely position and move controllers, researchers have recently developed ungrounded 3-DoF force feedback technologies based on propellers. Thor's Hammer [Heo et al. 2018] uses 6 orthogonal propellers to provide ungrounded 3-DoF force feedback, and is capable of generating 4.0N of forces at a weight of 692 grams. However, because propellers must physically spin up and slow down, it has a maximum impulse frequency of less than 2Hz, which is slower than many types of common haptic events.

We present JetController, a novel high-speed 3-DoF ungrounded force feedback controller capable of supporting the speed of human button presses and high-speed game events. It combines multiple compressed air jets as shown in Figure 1 to achieve composite forces in 3-DoF. By using high-speed pneumatic solenoid valves and circuitry, JetController can support full impulse frequency of 20-50Hz at 4.0-1.0N, which is more than 10 times faster than propeller-based approaches. Figure 1.c summarizes the frequency of several types of haptic events and ungrounded force feedback technologies, showing a wide range of haptic events in games and VR experiences supported by JetController.

2 SYSTEM DESIGN AND IMPLEMENTATION

To achieve high-speed impulses, we paired the Festo MHE4 high-speed solenoid valves, which are rated to have an operating frequency of 300Hz, with high-speed versions of the SMC ITV2050 pressure regulator to control air pressure. This system design is more than 10 times faster than prior pneumatic control systems, such as the 5Hz we achieved in HeadBlaster [Liu et al. 2020].

To create 3-DoF composite forces, 5 solenoid values are each connected to a noise-reducing nozzle, with 3 pressure regulators being used to adjust the air pressure for each of the 3 horizontal nozzles, as shown in Figure 2. Along Z-Axis, because the two vertical nozzles do not actuate simultaneously, we designed them to share a single regulator to reduce weight and complexity.

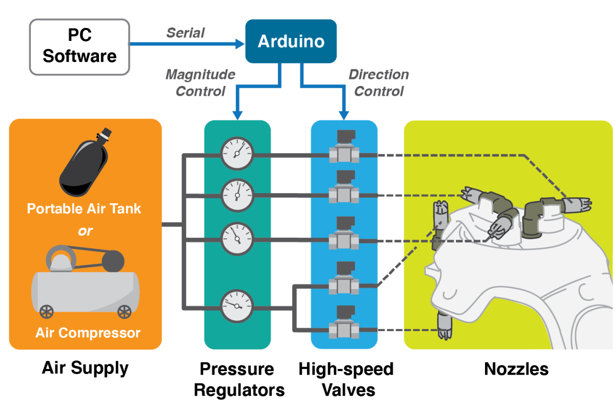

Figure 2: System architecture diagram showing 4 high-speed pressure regulators that control force magnitude, connected to 5 high-speed solenoid valves and air nozzles that control the force directions on a VR controller.

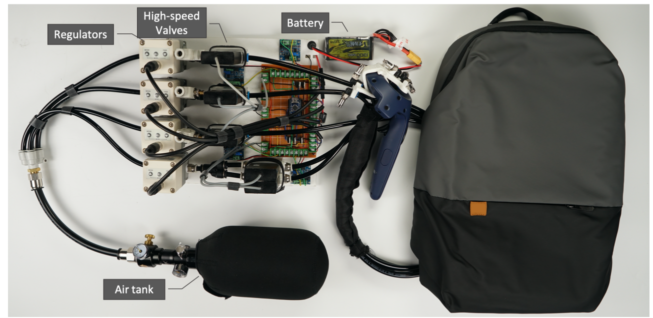

Figure 3: A mobile prototype of JetController that uses a high-pressure air tank and fits into a backpack. The dimensions of the backpack is 275x150x430mm.

The compressed air could be supplied from air compressors or from high-pressure portable air tanks, such as those used for paintball, as shown in Figure 3. In this portable design, the pneumatic control system weighs 4.8Kg, and can be carried in a small backpack. We have open-sourced the entire system, including 3D models, API, Arduino designs, at JetController.org [Wang et al. 2021].

3 HANDS-ON DEMONSTRATION

To demonstrate high-speed force feedback for a variety of 3-DoF interactions, we integrated JetController with two highly-rated, best-selling VR games, Fruit Ninja VR and Half-Life: Alyx, with commercial licenses purchased for demonstration via Steam.

3.1 Half Life: Alyx VR Game

We have designed 13 types of haptic events for shotguns, pistols, and submachine guns (e.g. firing, reloading, and inserting/ejecting magazines), as well as gravity gloves. An example high-speed haptic feedback is when firing the automatic submachine gun, which requires a haptic device to support an impulse frequency of 10Hz.

3.2 Fruit Ninja VR Game

To integrate with Fruit Ninja VR, we use OpenVR API to monitor the VR controller's status for vibration requests generated by the game, which can reach 45Hz when players quickly swing the sword to slice fruits in 3-DoF.

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