Demonstration of JetController: High-speed Ungrounded Force Feedback Controllers Using Air Propulsion Jets

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Figure 1: (a) JetController design for the Sony DualSense controller consists of one backward air nozzle, (b) provides recoil feedback by Adaptive Trigger, and (c) generating high-speed force feedback by JetController to support the tactile (surface texture) feedback in racing games. (note: the white smoke is only shown for illustrative purposes, and compressed air jets are invisible in actual use.)

ABSTRACT

JetController is a novel haptic technology capable of supporting high-speed and persistent 3-DoF ungrounded force feedback. It uses high-speed pneumatic solenoid valves to modulate compressed air to achieve 20-50Hz of full impulses at 4.0-1.0N and combines multiple air propulsion jets to generate 3-DoF force feedback. Compared to propeller-based approaches, JetController is more than 10 times faster in impulse frequency, and its handheld device is significantly lighter and more compact. JetController supports a wide range of haptic events in games and VR experiences, from firing automatic weapons in games like Halo to cutting fruits in Fruit Ninja. To discuss the differences between JetController and vibrotactile feedback approaches, we designed a new prototype based on PS5 Controller, DualSense [1]. There are three haptic approaches in our demonstration, JetController, Adaptive Trigger, and regular vibration feedback. We provide two scenarios, driving with tactile (surface texture) feedback and shooting with recoil feedback.

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CCS CONCEPTS

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

KEYWORDS

High-speed haptic feedback, air propulsion, ungrounded force feedback.

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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 digging holes in Minecraft, throwing turtle shells in Mario Kart, and cutting fruits in Fruit Ninja; while some are automatically provided as long as a button/trigger is held down, such as firing submachine guns in first-person shooter (FPS) games. The speed of human button presses ranges from about 6Hz for an average person to 16Hz for one of the world's fastest players [7]. For automatic weapons, the frequency is up to 10-15Hz in FPS games such as Halo and Half-Life.

Vibration motors, such as those based on eccentric rotating mass (ERM), have long been embedded into controllers to provide haptic feedback [6]. Linear resonant actuator (LRA) provides improved precision and faster response time to provide richer vibrotactile patterns, and are used in iPhone's Taptic Engine, modern console and VR controllers, such as Vive controllers. However, the fidelity of vibrotactile feedback is limited due to limited directionality.

To enrich the diversity of haptic feedback on handheld controllers, a new technique, Adaptive Trigger, has been applied to Sony's new console, PlayStation 5(PS5). DualSense, the official product name of PS5 Controller, is capable of rendering haptic feedback on its triggers. Custom-made geared motors inside the DualSense generate tension and high-frequency impact for its triggers.

To explore the differences between JetController, Adaptive Trigger and regular vibration feedback, we integrate a simplified JetController with a DualSense controller. Given the limited directionality of vibrotactile feedback, we removed 3-DoF force feedback capability to make the comparison fair. With a high-speed solenoid valve and circuitry, the DualSense version supports a backward full impulse frequency of 20-50Hz at 4.0-1.0N.

To manage noise and minimize weight, we selected miniature noise-reducing air nozzles that reduce noise by 65% [8]. The overall handheld weight, excluding the controller, is 43 grams with a volume of $61cm^3$.

We will display our prototype with two games in our demonstration, a first-person shooter and a racing game. Participants can experience JetController, Adaptive Trigger, and regular vibration feedback separately in each game.

2 JETCONTROLLER

2.1 Nozzle Holder for Controller Integration

Our design goal for JetController is to support existing VR and console controllers in a light-weight and compact form factor such that users can use the controllers as usual. In this demonstration, we present our design for the PS5 controller as an example.

To create a light yet durable device, we custom-designed a nozzle mount for PS5 Controller and printed them with a Ultimaker S5 3D Printer using Tough PLA material. The nozzle and the 3D printed mount are shown in Figure 1.

2.2 Handheld Weight and Size

The handheld portion of JetController consists of a nozzle, a mounting clip, and tubing. We selected the miniature Silvent 1001 nozzle to reduce noise, which is rated to reduce noise by 65%, and weigh 8 grams each with tubing connector. The 3D printed nozzle mount weigh 16 grams and the 6mm tubing weighs 19 grams/meter. Connected with 1 meter of 6mm tube, the total weight of the handheld portion on JetController is 43 grams.

We estimate the size using minimal bounding boxes. The nozzle and the mounting clip are 70mm x 70mm x 5mm, while the 6mm tubing wrapped together are 1000mm x 6mm x 6mm, for a total volume of $61cm^3$ combined.

2.3 Pneumatic Control System

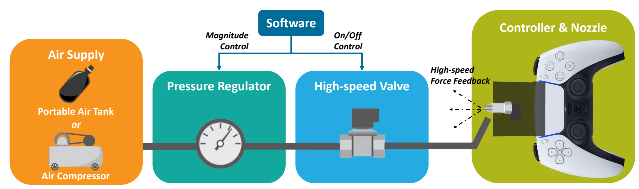


Figure 2: System architecture diagram showing a high-speed pressure regulator that controls the force magnitude for the high-speed solenoid valve to control the force impulse, connected to the front air nozzle mounted on the PS5 controller.

To enable high-speed impulses and persistent force feedback, we experimented with several proportional values, pressure regulators, solenoid valves, and combinations of them. We selected the Festo MHE4 high-speed solenoid valves rated to have an operating frequency of 300Hz while supporting sufficient airflow to generate more than 4.0N of propulsion force. The air pressure is controlled using high-speed versions of the SMC ITV2050 electro-pneumatic pressure regulator.

An Arduino Nano is used to control the regulator and the solenoid valve. For more details on the prototype, please refer to the original paper.

The compressed air could be supplied from air compressors or high-pressure air tanks, such as those used for paintball.

2.4 Impulse Frequency

To measure impulse frequency, we attached one nozzle to an L-Shape fitting and mounted it on an IMADA ZTS-20N load cell, which can record data at 2000Hz at up to 20N with an accuracy rating of 0.2% full scale (0.04N). We benchmarked two tubing size (diameter 6mm vs. 8mm) and two tubing lengths (100cm vs. 250cm), for a total of 4 configurations. An air compressor is used to provide stable input pressure of at least 0.9 MPa. We applied a low-pass filter on data points to identify maximum force and calculated the maximum value. After the maximum force was found, we measured the rise time and fall time as the periods from the 10% to 90% and 90% to 10% of the maximum force value respectively, based on a standard approach to calculating rise time and fall time of analog impulses [4]. Figure 3 shows the maximum impulse frequencies for four tubing configurations at 1N, 2N, 3N, and 4N, calculated based on the rise time and the fall time. For example, the combined rise and fall time for 6mm x 100cm tubing is 18ms, equivalent to 55.4Hz. It shows that shorter tubing consistently achieves higher frequency at the same tubing size for both 6mm and 8mm tubing because a smaller air volume is needed to be filled and released. However, the effect of tubing size on impulse frequency is more complicated. Larger 8mm tubing sometimes has higher frequencies and sometimes has lower frequencies than smaller 6mm tubing with the same length. Overall, 6mm x 100cm tubing provides the highest frequency for 1.0N at 55.4Hz, and 8mm x 100cm tubing provides the highest frequency for 4.0N at 20.5Hz.

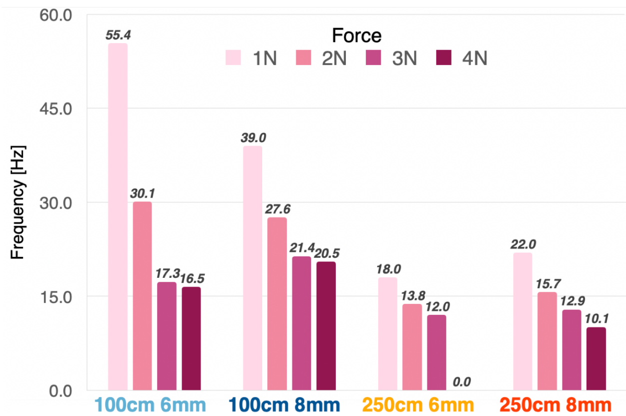


Figure 3: Maximum impulse frequency at different force magnitudes for different tubing sizes and tubing lengths, calculated based on force rise time and fall time. (The 4.0N frequency is unavailable for 6mm x 250cm tubing because it could only achieve a maximum force of 3.3N.)

To demonstrate and validate that our system can indeed achieve these high-speed impulse frequencies, we programmed our system to generate 50Hz of full impulses at 1.0N and 20Hz at 4.0N, and show the load cell measurements in Figure 4.

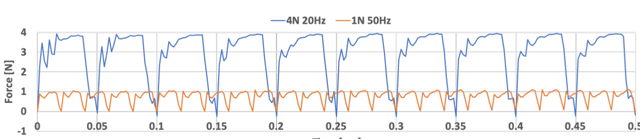


Figure 4: Actual force curve measurements of JetController, showing 50Hz of full impulses at 1.0N (6mm x 100cm tubing) and 20Hz of full impulses at 4.0N (8mm x 100cm tubing).

2.5 Noise

To measure the noise level, we placed a WS1361C decibel meter at a 1-meter distance from the nozzle. All experiments took place in an unoccupied office with concrete walls, and the base ambient noise level was measured to be 51 dB.

The use of nozzles significantly reduced noise level, and the noise level ranges from 67dB to 80dB for forces from 1.0-4.0N. According to Centers for Disease Control and Prevention (CDC), USA, 80-85dB is equivalent to city traffic (inside the car), 70dB to "Washing machine, dishwasher", and 60dB to "Normal conversation, air conditioner".

3 HANDS-ON DEMONSTRATION OF JETCONTROLLER

In our demonstration, we choose a quiet air compressor rated at 40dB-60dB for use in quiet locations, which range from the noise level of refrigerator hum (40dB) to normal conversation (60dB). Our measurement shows the loudest operating noise of the air compressor is 59.8dB, which is equal to normal conversation and is safe for humans [2].

To show the benefit of high-speed force feedback and to explore the differences among JetController, Adaptive Trigger and regular vibration feedback, our demonstration focuses on comparing feedback these three approaches generate, which will be displayed separately.We modified open-sourced DualSense control kit [9] to manipulate vibration motors and the Adaptive Trigger.

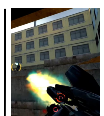
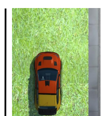
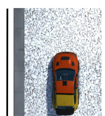
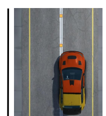
Haptic Events	 10Hz Firing	 Driving on grassy roads	 Driving on stony roads	 Driving on road studs
Vibration Motors	Heavy Motor 43% Light Motor 43% 100ms ON 0ms OFF (Default Pattern in Game)	Heavy Motor 25% Light Motor 100% 10ms ON 30ms OFF	Heavy Motor 100% Light Motor 0% 15ms ON 65ms OFF	Heavy Motor 100% Light Motor 13% 20ms ON 65ms OFF
Adaptive Trigger	10Hz Vibration On Right Trigger	30Hz Vibration On Right Trigger	10-20Hz Vibration On Right Trigger (Depends on car speed)	1-7Hz Vibration On Right Trigger (Depends on car speed)
JetController	3N 10Hz 50ms ON 50ms OFF	1N 30Hz 18ms ON 15ms OFF	1.6N 10-20Hz 25ms ON 25-75ms OFF (Depends on car speed)	3N 1-7Hz 50ms ON 92-950ms OFF (Depends on car speed)

Figure 5: Haptic events in our demonstration.

We integrated our prototype with two scenarios, driving with tactile feedback and shooting with recoil feedback, as shown in Figure 5. Since the scenarios may contain 50Hz force feedback, we choose the 6mm x 100cm tubing configuration for our demonstration. To manage noise from affecting the haptic perception, a set of Sony WH-1000XM3 active noise-canceling headphones will be used during the demonstration.

Consistent with the findings in HeadBlaster [3], these noise-canceling headphones with white noise could sufficiently mask the air jet noises that noise from air jets was barely noticeable.

3.1 Driving with tactile feedback

Several racing games provide haptic feedback by using controllers' vibration motors. When a car is driving on roads with a fine surface texture, such as grass roads or dirt roads, controllers will generate high frequency yet low amplitude vibration. For driving on stony roads, controllers tend to provide stronger vibration feedback. Another example is road studs, which give tactile feedback for drivers. Road studs are installed on roads; when players drive cars on road studs, controllers also generate strong vibration feedback.

In our demonstration, we made a 2D driving game with Unity. There are four kinds of textures in our game, an asphalted texture, a stony texture, a grassy texture, and a texture filled with road studs.

Our game supports JetController, Adaptive Trigger, and vibration motors. We will demonstrate these haptic techniques separately, so participants can feel the differences between each kind of haptic feedback.

3.2 Shooting with recoil feedback

Half-Life 2 is an all-time highest-rated game according to MetaCritic, a respected game rating aggregator [5]. We purchase the commercial license on Steam [10] for this demonstration. In this scenario, participants press the right trigger for firing the automatic submachine gun. To simulate the recoil, we write a program to monitor the rumble requests from the game engine. When a rumble request is intercepted, we can make the controller vibrates, actuate the Adaptive Trigger, or generate force feedback by JetController. In Half-Life 2, firing the automatic submachine gun requires a haptic device that supports an impulse frequency of 10Hz. Since our prototype can provide more than 4.0N 10Hz in practice, participants can feel stronger feedback than vibrotactile patterns and Adaptive Trigger feedback.

4 CONCLUSION

We propose JetController, an ungrounded force feedback device capable of supporting the speed of human button presses and even automatic weapons' rapid firing speed. We provide two game applications for participants to experience high-speed force feedback with three different haptic techniques, JetController, Adaptive Trigger, and vibrotactile feedback.

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