ShockShot: Enhancing Gunfire Immersion with Real-Time Sensory Feedback*

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Abstract

This paper proposes the "ShockShot" system, which incorporates a real gunpowder-based firing mechanism to provide a more immersive and realistic shooting experience in a mixed reality (MR) environment. The system utilizes a shock sensor to measure firing time accurately and includes a controller with six degrees of freedom tracking. A user study (N = 17) compared ShockShot with commercially available haptic devices of similar shape. Results indicated that tactile, visual, and olfactory feedback—closely replicating the actual shooting experience—significantly increased user immersion and satisfaction, without causing statistically significant increases in fatigue. These findings suggest that integrating real physical mechanisms into MR environments can overcome the limitations of existing digital feedback, presenting a novel and richly sensory shooting experience.

1 Introduction

Mixed reality (MR) integrates digital and physical environments, enabling real-time interactions with virtual objects [18]. Rapid developments in MR are offering immersive experiences across various domains, including gaming [11, 14], education [31], and training simulations [17].

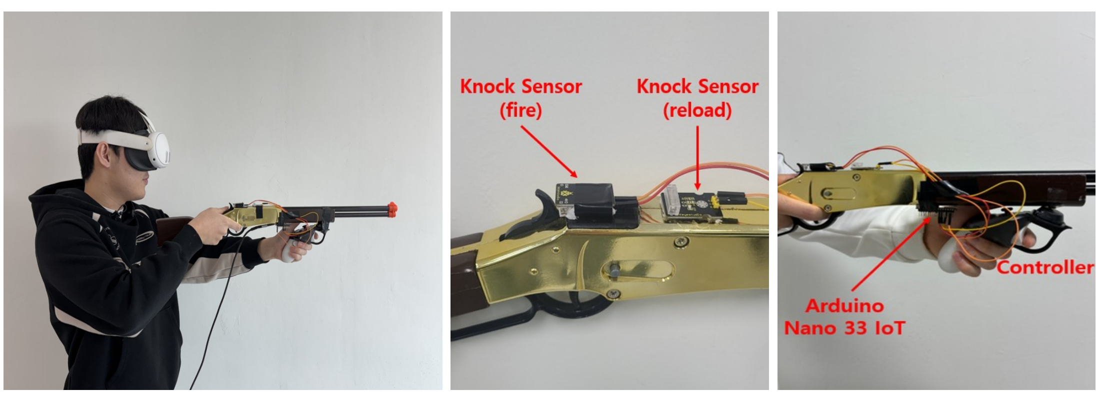

Figure 1: ShockShot provides immersive sensation in mixed reality first-person shooter environments using a real gunpowder-based firing mechanism.

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Current MR developments are predominantly focused on audiovisual integration, which forms the bedrock for immersive experiences and enhanced realism. This development is evidenced by a growing body of research aimed at blurring the boundaries between virtual environments and the real world through haptic technologies [7, 9, 25, 12].
Haptic feedback plays a crucial role in enabling realistic physical interactions within virtual environments [23, 8, 32]. It encompasses tactile and force feedback mechanisms that simulate physical sensations when users interact with virtual objects [33]. Although these methods effectively stimulate the sense of touch, they fall short of fully replicating the sensation of real-world physical interactions [15, 19, 21, 2]. Specifically, gun-shaped haptic devices employed in MR shooting games frequently fail to reproduce the sensory complexity associated with actual firearm use [24, 5]. Therefore, we propose ShockShot, a novel haptic device that utilizes a gunpowder-based firing mechanism to enhance immersion in the MR environment. The system incorporates a lightweight, sensor-based design that accurately detects the movement of the gun and synchronizes it with the MR environment. Figure 1 shows an overview of the ShockShot system and its usage in an MR FPS environment. This integration supports more intuitive and natural interaction with the virtual environment, providing a novel MR shooting experience that overcomes the limitations of conventional haptic devices. Furthermore, entertainment oriented MR shooting games, the proposed approach can serve as a foundation for more immersive training, virtual entertainment systems, and experience-based education, where fine-grained, multi-modal physical feedback is crical fitor skill acquisition, procedural memory, and affective engagement. To assess the efficacy of ShockShot, a user study (N = 17) was conducted comparing its sensory effect with that of a commercially available gun-shaped haptic device within the same MR shooting game environment. ShockShot received favorable evaluations in terms of enjoyment, user satisfaction, and immersion. The key contributions of this paper are as follows:

1. Developing a physical mechanism that mirrors the use of a real gunpowder gun, achieving synchronization with the MR environment.

2. Providing a more realistic shooting experience by integrating various sensory elements, thereby expanding the scope of sensory feedback in MR applications.

2 Related Work

2.1 Gun-Shaped Haptic Device

Gun-shaped haptic devices are designed to enhance the user's physical experience by replicating the form factor and handling characteristics of real firearms. These devices aim to preserve the ergonomic and tactile characteristics of real guns, thereby facilitating more natural and intuitive interactions within virtual environments[16]. Early studies have shown that such devices can significantly improve immersion in virtual reality (VR) applications, particularly in scenarios involving firearm interaction [10].
Various gun-shaped haptic devices have been developed to incorporate various physical feedback mechanisms [27, 15, 24, 19, 26], providing a high-fidelity reproduction of the sensory experiences encountered during firearm operation, such as firing, recoil, and reloading. Despite notable advancements in this field, existing gun-shaped haptic devices primarily focus on simulating recoil [27, 15, 19, 20] and maintaining realistic form factors. However, these efforts often result in a discrepancy in realism when compared to actual firearms. Furthermore, the reloading

mechanisms are often oversimplified or abstracted, reducing the overall fidelity and realism of user interactions.

2.2 Nondigital Senses

Nondigital sensory experiences refer to various forms of physical and sensory feedback that enhance user perception and immersion without relying on digital technology [?]. These experiences encompass sensations that are inherently challenging to replicate through purely digital means, such as physical textures, temperature variations, tangible weight, and olfactory stimuli. By engaging these senses, users are better able to perceive and interpret virtual environments as extensions of reality. For instance, vibration modules and pressure sensors can simulate tactile experiences, thereby enhancing user engagement and the overall sense of realism [13].

A growing body of research has recently emerged that explores the integration of nondigital sensory elements—beyond sight and hearing—into VR systems [3, 4, 1, 6]. The integration of tangible physical elements helps mitigate the perceptual gap between real and virtual worlds, facilitating a more natural and immersive experience. As noted in [29], nondigital multisensory feedback serves as a crucial conduit between the digital and physical domains, enhancing realism in virtual environments.

These strategies can also be applied to FPS environments. Key nondigital sensory elements in such contexts include the actual weight of weapons, visible smoke, the smell of gunpowder, and the manual reloading process. These elements are important for enhancing the immersion and realism of the virtual experience. However, most existing research has focused on tactile and pressure-focused nondigital sensation with relatively few studies exploring the integration of other sensory modalities beyond sight and hearing. Consequently, a key challenge lies in formulating strategies for the seamless and effective integration of these supplementary sensory components within FPS environments to achieve a truly multifaceted and immersive user experience.

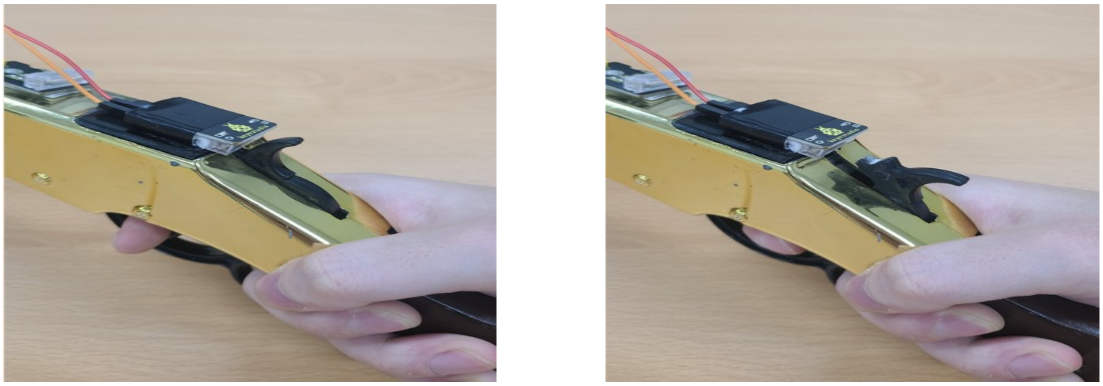
3 System Implementation

3.1 Hardware Implementation

The hardware configuration consists of an Arduino Nano 33 IoT, two knock sensors, a gunpowder gun, and a MetaQuest3 controller. The Arduino Nano 33 IoT facilitates communication between the knock sensors and the head-mounted display (HMD). To mitigate the necessity for modifications to the firearm's exterior or internal structure, the knock sensor and electronic components are mounted on a custom removable mount positioned on the top or side of the gun that can be attached to the exterior. The Arduino was powered directly via the HMD, although battery operation was also supported as an alternative configuration. MetaQuest 3 served as the HMD platform. The final dimensions of the ShockShot prototype were $(W, D, H) = (70, 16, 8)$cm.

3.1.1 Gunfire System

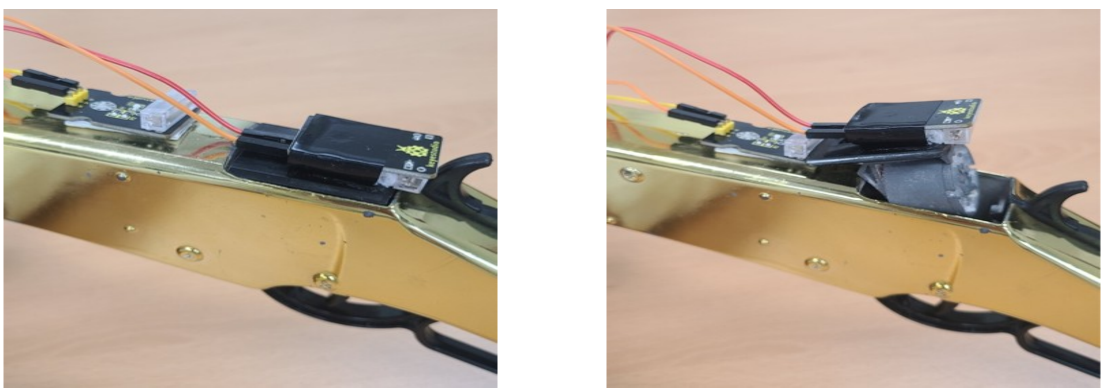
In the ShockShot system, it is important that the real gun fires in real time within the virtual environment. To achieve this synchronization, a knock sensor was affixed to the location shown in Figure 2, with the objective of accurately capturing the precise moment of firing. If the sensor is attached as illustrated, it fail to operate correctly due to internal resistance encountered as



(a) (b)

Figure 2: Gunfire process: (a) state before and after firing and (b) state during firing.

the trigger moves from the position illustrated in Figure 2(a) to that in Figure 2(b). However, when the trigger is fully pulled, it moves forward rapidly, delivering a strong impact to the knock sensor. This is immediately followed by the discharge of the gunpowder-based gun.



(a) (b)

Figure 3: Reload process: (a) state before and after reloading and (b) state during reloading.

3.1.2 Reload System

In the ShockShot system, a physical reloading system was developed to enhance realism. ShockShot incorporates a reload system using a shock sensor positioned in the location depicted in the accompanying illustration. Reloading is initiated by the movement of a protruding black plastic part during the transition from Figure 3(a) to Figure 3(b). As this movement begins, the shock sensor detects the impact, and the software registers the reloading action accordingly. After that, the user replaces the gunpowder and closes the black plastic part.

3.2 Software Implementation

3.2.1 Arduino Firmware

Figure 4 shows the workflow of the ShockShot system. The device is equipped with a knock sensor that converts the physical impact generated by the movement of the gun into a digital signal. The Arduino Nano 33 IoT is programmed to receive this signal in real time and immediately transmit a BLE notification upon detecting a firing or reloading event. To ensure reliability, the system design incorporates internal resistance and an event debounce mechanism to minimize the effects of microvibrations and external noise. A threshold-based triggering mechanism is employed such that only significant impacts are registered as valid events.

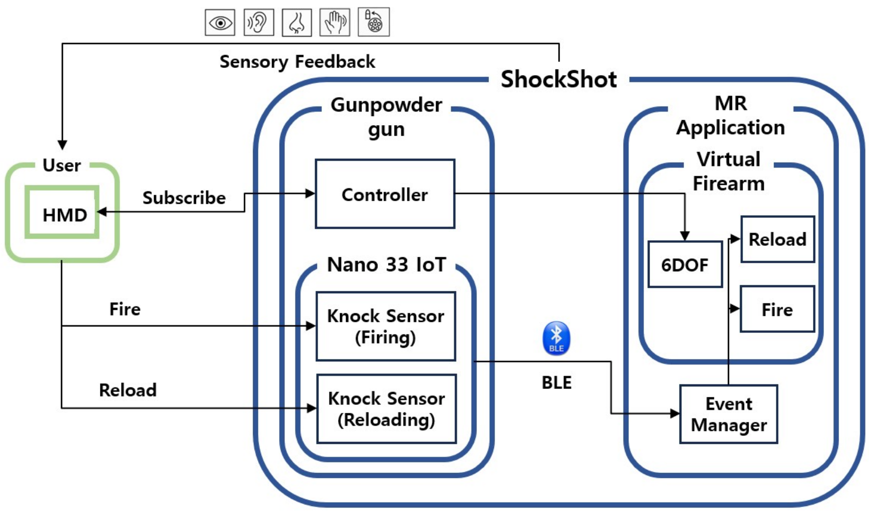


Figure 4: System workflow.

3.2.2 MR Application

When the user fires and the event is detected by the knock sensor, the data are transferred via the Arduino's BLE module, and the bullet is immediately fired within the game engine. A similar process is followed during reloading, with the software simultaneously updating the current number of bullets. From the user's perspective, the firing and reloading systems are perceived as immediate, with minimal perceptible difference between the physical and virtual firing times. However, in rare cases where the gunpowder misfires but the trigger mechanism still moves and the sensor detects the impact, a firing event may still be triggered in the virtual environment. This constitutes a current technical limitation of the system, and corresponding improvements are presented in Section 6, Discussion.

4 Study

A user study was conducted to investigate the ability of ShockShot to provide various sensory experiences. Specifically, the study aimed to determine whether users could perceive the various sensory stimuli provided by ShockShot and whether these stimuli contributed to enhanced fun and immersion. To this end, a comparative study was performed. ShockShot was compared with a commercially available gun-shaped haptic device [28], using an identical MR gaming process for both devices. A gun-shaped haptic device contains only vibration capabilities. The final dimensions of the gun-shaped haptic device were $(W, D, H) = (41, 11, 8)$cm.

4.1 Participants

An experiment was conducted with 17 participants, comprising 13 males and 4 females, aged between 22 and 26 years (M = 24.2, SD = 1.1). Participants' prior VR experience was categorized into three levels: high (currently using VR), medium (previously used VR), and low (only briefly experienced VR). We also surveyed participants with prior experience firing a real gun to assess perceived realism; a total of 12 participants reported having done so. Each participant received a reward of approximately $10.

Table 1: Survey questionnaire.

No.	**Aspect**	**Question**
1	Fun	How much fun did you have while playing?
2	Satisfaction	How satisfied are you with the feedback provided?
3	Fatigue	How fatigued were you while playing?
4	Immersion	How immersive were you while playing?
5	Preference	Which device is preferred?

4.2 Design

To evaluate the enhancement of the sensory experience, we conducted a comparative study between ShockShot and a commercially available gun-shaped haptic device. we used software-based effects such as muzzle flash and smoke particles to ensure consistency across both systems. Participants were asked to respond to four questions comparing the two methods using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Table 1 shows the questions used in the survey. In addition to rating these items, respondents were asked to indicate their preferred method—ShockShot or the commercial gun-shaped haptic device—and were invited to provide any additional comments.

4.3 Procedure

ShockShot was previously tested in a user study involving a defense game where participants were tasked with shooting flying monsters with a gun. Participants played the game until they had fired 24 shots (8 x 3), which required two reloads. Before beginning, the experimenter explained the entire procedure, including safety precautions, and demonstrated how to aim, fire, and reload the gun. Participants then donned the HMD, and the two experimental conditions using the commercial gun-shaped haptic device and ShockShot were conducted in a counter-balanced order.

Each participant fired a total of 24 rounds (8 x 3), reloading twice during the game. The experiment using the commercial haptic device lasted approximately 3 min, whereas the ShockShot trial took approximately 7 min. Upon completing the two experiments, participants filled out a survey. The entire session lasted approximately 25 min per participant.

	ShockShot		Gun-shaped haptic device	
	Mean	SD	Mean	SD
Fun	4.176	0.809	3.824	0.951
Satisfaction	4.235	0.831	3.529	0.717
Fatigue	3.118	1.269	3.588	1.176
Immersion	4.412	0.618	3.824	0.951

Table 2: Survey results comparing ShockShot and the gun-shaped haptic device.

4.4 Results

4.4.1 Subjective Scores

Table 2 shows the results of the questionnaires evaluating fun, realism, fatigue, and immersion. The mean scores are visible as ‘x’ in the diagram for reference. The fatigue score was corrected such that higher values indicated lower fatigue and were thus considered better. As the Shapiro–Wilk test [22] indicated non-normal distribution across all measures, the Wilcoxon signed-rank test [30] was employed for statistical tests. The ShockShot group scored higher in all areas except fatigue. Notably, ShockShot had a significant effect on satisfaction ($p < 0.05$, $r = 0.543$) and immersion. Immersion ($p < 0.005$, $r = 0.681$), the primary focus of the study, showed a particularly significant result. In addition, no significant difference was found in fatigue between the two groups ($p > 0.05$), alleviating concerns about physical strain. However, no significant difference was observed in the fun factor ($p > 0.05$). In contrast, users with prior VR experience (N = 7) showed a significant difference in the fun factor ($p < 0.05$, $r = 0.782$). suggesting that first-time VR users might have perceived the VR experience itself as sufficiently fun.

4.4.2 Subjective Comments

Participants were asked to provide additional comments on the ShockShot system. A majority of participants reported positively that ShockShot enhanced their sense of immersion (eight participants) and realism (three participants), with several noting that the reloading process contributed positively to this immersive experience. However, two participants felt that the reloading process was time-consuming and detracted from the overall immersion.

Regarding device preference, 11 participants preferred ShockShot, whereas six preferred the gun-shaped haptic device, as shown in Figure 8. Those who preferred the commercial haptic device cited the quicker firing process (two participants) and found ShockShot to be overly complicated (two participants). Additionally, two female participants expressed discomfort, noting they felt uneasy handling the ShockShot device.

5 Conclusion

In this study, we introduced ShockShot, a haptic device designed to integrate firearms into MR environments to enhance immersion and realism. ShockShot employed the construction of a real firearm and a gunpowder-based firing mechanism to provide multisensory feedback, including muzzle flash, the smell of gunpowder, smoke, and a reloading system. By bridging the gap between real and virtual interaction, ShockShot provided a more realistic MR shooting experience.

To evaluate its effectiveness, we conducted a user study (N = 17) comparing ShockShot with a traditional gun-shaped haptic device. The results showed that ShockShot significantly increased users' sense of immersion and satisfaction without causing excessive fatigue. Our approach demonstrated the potential of incorporating real physical devices into virtual environments to provide interactions that extend beyond digital feedback, offering a new direction for enhancing tactile realism in MR applications.
Future work will extend this approach beyond firearms to other haptics (e.g., welding, chainsaws, and power tools), exploring how volatile cues and physical actuation can generalize tactile realism across domains.

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