Virtual Reality-Based Gymnastics Visualization Using Real-Time Motion Capture Suit

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***Abstract*—Gymnastics imposes great physical and mental stress on its athletes. Whether due to injury, fatigue, or a desire to rest before a competition, gymnasts cannot always practice their skills successfully and safely in training. To account for this, gymnasts often close their eyes and imagine themselves performing their moves to train focus and muscle memory without excessive physical exertion. This paper presents a system that allows gymnasts to take this a step further by controlling a virtual gymnast from the first-person perspective in virtual reality (VR). When operating the system, the user wears a full-body motion capture suit and a VR headset. The user controls a virtual gymnast using gestures tracked by the suit and perceives an immersive virtual environment through the VR headset. To ensure a fruitful user experience, the virtual environment must be immersive and realistic. First, the virtual gymnastics movements must mimic those of real life. Second, the system must have a high image-rendering speed, dropping no lower than 60 frames per second. Third, real-life movements must correspond to virtual movements nearly instantly, so the motion-to-display (MTD) latency should be minimized. In this paper, we demonstrate that the system's virtual gymnastics animations are derived directly from moves performed in real life using motion capture suit. Additionally, the system achieves an average frame rate of 71.46 frames per second and an average MTD latency of 59.31 ms.**

I. Introduction

The sport of gymnastics puts extreme stress on the minds and bodies of its athletes. It is common for gymnasts to experience fatigue, injuries, and mental blocks during training [1], rendering them unable to perform certain movements successfully and safely. When this happens, gymnasts are often instructed to visualize their moves instead of physically performing them. Visualizing a gymnastics move typically entails closing one's eyes and imagining oneself performing the move from a first-person perspective. As shown in Fig. 1, visualization is often accompanied by small arm, leg, and hip movements intended to mimic the muscle contractions necessary to perform the move in real life. Though certainly not a substitute for physically practicing skills and routines, visualization helps gymnasts maintain muscle memory and train focus when extreme physical exertion is unrealizable.

In this demo, a system is demonstrated that intends to make a gymnast's visualization experience on the pommel horse more immersive and fruitful with the help of virtual reality (VR) and motion capture technology. The user controls a virtual gymnast's actions from the first-person perspective using the small arm, hand, and hip movements. The specific gestures recognized by the system mimic the muscle contractions executed by gymnasts when performing skills on the pommel horse in real life, helping the user train focus and muscle memory without undergoing intense, potentially dangerous physical activity.

Fig. 1: A gymnast visualizes a pommel horse move on the left and physically performs the move on the right.

To provide the user with an immersive, lifelike visualization experience, a few benchmarks must be satisfied. First, the virtual gymnast's movements when performing on the pommel horse must closely mimic those executed by gymnasts in real life. Second, the system must provide high-speed image rendering, allowing the user to experience the virtual environment in greater than 60 frames per second. Third, the system must guarantee minimal motion-to-display (MTD) latency. Real-life movements must be observed in the virtual environment nearly instantaneously; delays greater than 20 ms may be apparent to the user and reduce immersion [2]. For the most part, the system demonstrated in this paper achieves these goals, but the MTD latency can be further improved in the future.

II. System Architecture

This section presents a design for a virtual reality-based gymnastics visualization tool. The tool allows the user to experience various moves on the pommel horse from a first-person perspective using the small arm, hand, and hip movements that mimic those executed on pommel horse in real life. As depicted in Fig. 2, the system consists of a PC, a Wi-Fi router, a VR headset, and a real-time full-body motion capture suit. The Wi-Fi router is connected to the PC via Ethernet cable. The VR headset communicates with the PC either via Wi-Fi or a USB cable. When operating the system, a user wears both the motion capture suit and the VR headset. The suit wirelessly transmits the user's position and motion data to the PC via the Wi-Fi router. The PC maps this motion capture data to a virtual character and tracks the character's interactions with other objects in the virtual gymnastics environment. The PC transmits this information to the VR headset, immersing the user within the virtual environment. Additionally, information tracked by the headset, such as camera position and controller input, can be sent back to the PC to be processed and implemented in the virtual environment.

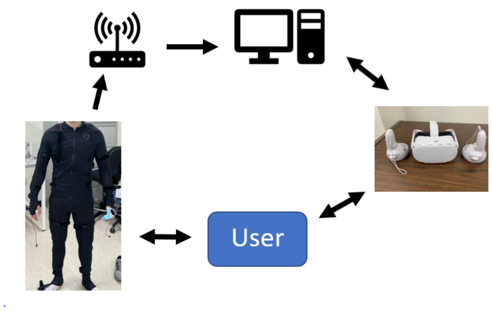


Fig. 2: System architecture.

III. Demonstration

The system is deployed using a TP-Link Archer AX50 router wired to a PC containing an Intel(R) Xeon(R) Gold 6242R CPU @ 3.10GHz, NVIDIA Quadro RTX 5000 Graphics Card ×2, 128 GB memory, and Windows 10. Motion capture data is gathered and transmitted using a Rokoko Smartsuit Pro II along with Rokoko Smartgloves for hand tracking. An Oculus Quest 2 VR headset is used with its associated Oculus Touch controllers. A USB 3.0 cable transmits data between the headset and PC via Oculus Link.

Fig. 3 shows a user performing gymnastics within the virtual environment. Lowering the user's hand within a certain range of a virtual pommel and squeezing the corresponding Oculus Touch controller causes the virtual gymnast to perform an appropriate fraction of the desired gymnastics move. The user repeats this action with the other hand to complete the next part of the move. Doing this in an alternating fashion allows the gymnast to smoothly perform the moves desired by the user. A demo video is available at [3].

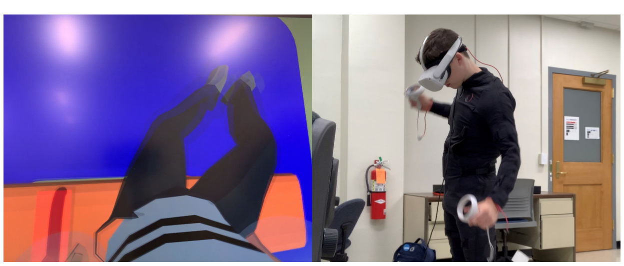
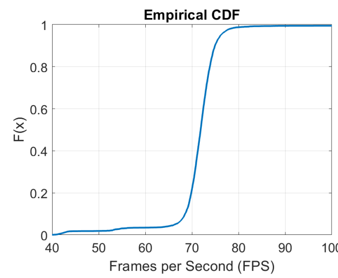
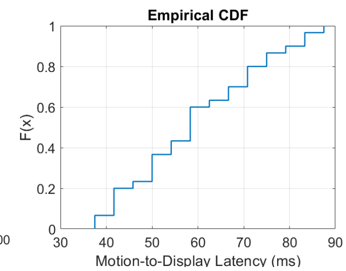


Fig. 3: First-person virtual pommel horse move pictured on the left and associated user action pictured on the right.

Recall that our goal in this system is to let the virtual gymnast smoothly and accurately imitate those actions performed in the real world. To get the evaluation results, we let a user perform real gymnastics moves while wearing the Rokoko Smartsuit Pro II to gather animations for the virtual gymnast. Then, we evaluate the proposed system with two metrics: frame rate and MTD latency. As for the frame rate, we run the system for five times, and gather 1000 samples of the time intervals between adjacent frames in each trial. The MTD latency in our system is defined as the time difference between the user's real-world action and its reflection on the virtual avatar. To estimate this latency, we perform a small arm movement 30 times and capture each trial by a camera recording at 240 frames per second. Upon playback of each trial, the number of frames between the beginning of the real-life arm movement and that of the corresponding virtual arm movement was counted and multiplied by 4.167 (1/240) ms to determine the latency. Note that this is a somewhat imprecise method intended merely to obtain a rough estimation.



(a) CDF of Frame Rate



(b) CDF of Motion-to-Display Latency

Fig. 4: Performance evaluation.

Fig. 4a and Fig. 4b depict the empirical cumulative distribution function (CDF) of the frame rate and MTD latency, separately. The system achieved an average frame rate of 71.46 frames per second and an average MTD latency of 59.31 ms. We believe the MTD latency mainly lies in the wireless communication latency between the motion capture suit and the router and leave the improvement on it as the future work.

IV. Conclusion

This paper demonstrates a virtual reality-based tool that uses a real-time motion capture suit to help gymnasts practice moves on the pommel horse without extreme physical exertion. Small arm, hand, and hip movements that mimic real-life pommel horse movements allow the user to control a virtual gymnast in VR from the first-person perspective. The system ensures an immersive, realistic user experience by employing animations gathered from motion capture data of real gymnastics moves, guaranteeing a frame rate greater than 60 frames per second, and limiting motion-to-display latency to tens of milliseconds.

V. Acknowledgements

This work has been supported in part by NSF under the grants CNS-2221897 and CNS-2152610.

References

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