Mo2Hap: Rendering performer's Motion Flow to Upper-body Vibrotactile Haptic Feedback for VR performance

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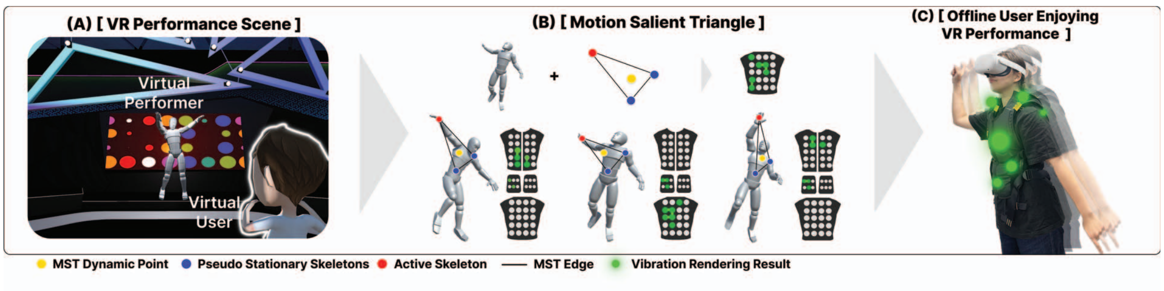

Figure 1: Our system supports (A) Virtual Reality (VR) performance scene, in which virtual performer dances and virtual users watch. We propose (B) a haptic rendering approach using salient motion points which translates the performer's motions into (C) upper-body vibrotactile haptic feedback.

Abstract

We present a novel haptic rendering method that translates the virtual performer's motions into real-time vibrotactile feedback. Our method characterizes salient motion points from proposing system **Motion Salient Triangle** to generate haptic parameters to highlight the performer's motions. Here, we employ an entire upper-body haptic system that provides vibrotactile feedback on the torso, back, and shoulders. We enable immersive virtual reality (VR) performance experiences by accommodating the performer's motions on top of motion-to-haptic feedback.

Index Terms: Human-centered computing—Haptic Device—Virtual Reality;

1 Introduction

Due to limited physical space and time, VR performances have emerged recently, and the advancement of VR performances has refined the meaning of *participation*. However, there were some limitations in not being able to feel *the sense of realism*, *immersion*, and *interaction with artists*. To overcome these limitations, previous research improved the motions of virtual avatars to enhance the sense of realism [4]. Nevertheless, direct interaction between performers and individual audiences is still absent. This research aims to create a pipeline of rendering a performer's 3D motions with depth data into high-quality haptic feedback for audiences wearing haptic displays. Motion Salient Triangle **(MST)** is the proposed algorithm, a three-dimensional triangulation calculated in real-time. It defines the salient point, **MST Dynamic Point**, and utilizes it for adjusting intensity and location parameters for vibrotactile feedback. With our novel proposing system, we expect users to interact with performers in a virtual environment actively.

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2 System Design Overview

2.1 Performer Motion Analysis

To understand the tendency of motions carried out by performers in both offline and online (VR) performances, we investigate the 156 minutes(41 video clips) of recorded concert videos. We picked video data based on popularity (Billboard Hot 100 chart). By analyzing motions manipulated throughout the performance, motions can be categorized into "choreography" and "highlight motions". Here, "highlight motions" indicate functions to share their emotions and nonverbal communication between audiences [2], *e.g. handing a mic, induce clapping*. Choreography refers to a technique of combining movements and performing them in dance. Insights from this survey, motions were mainly drawn through upper body movements, which requires a robust rendering algorithm to support the above behaviors converted to upper-body vibrotactile haptic feedback.

2.2 Motion Salient Triangle (MST)

Previously, research suggested a visual saliency map that works only using RGB 2D image data together with acoustic features [3]. In our case, we employ 3D data to expand the dimension while distinguishing the position coordinate of performers' consecutive motions.

MST is a novel real-time approach utilizing 3D coordinate and orientation values from skeleton data consisting of 32 joints (acquired from Azure Kinect DK). Figure 1 (B) illustrates the overall concept of the **MST**. At first, we define the skeleton joint that has the highest kinetic energy value as a *Active Skeleton*. The asymmetric skeleton of *Active skeleton*, located in the opposite shoulder is defined as *Root Skeleton*. Then, we calculate the performer's upper body's *center-of-mass*. *Root Skeleton* and Torso's *center-of-mass* points can be grouped as the *pseudo steady skeletons* that have low kinetic values. By concatenating these three points, a single 3D polygon which we name **MST** is created as shown in Figure 1 (B). As **MST** renders motion-reactive vibrotactile feedback, we expect the **MST** to fully express the performer's motions for the VR remote performances.

To adaptively render the flow of **MST**, we compute the **MST Dynamic Point** through Equation (1). Then render the vibrotactile intensity and location using the use of **MST Dynamic Point**. By multiplying weight, preliminarily starting from fundamental value,

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(w_{Active}, w_{Root}, w_{Torso} = *1*) to each coordinate. DP represents Dynamic Point and N signifies each skeleton's *x,y,z* coordinates.

$$DP_N = \frac{(A_N - C_N) \cdot w_{Active} + (T_N - C_N) \cdot w_{Root} + (R_N - C_N) \cdot w_{Torso}}{w_{Active} + w_{Root} + w_{Torso}} \quad (1)$$

$Centroid_N$, (C_N) refers to centroid point in **MST**, A_N connotates $Active_N$, R_N implies $Root_N$. T_N refers to $Torso_N$.

2.3 Translating tactile Intensity and Location

Regarding an immersive vibrotactile haptic sensation, controlling the intensity and location of the haptic proxy is necessary. Therefore, we focused on intensity and location values as parameters to effectively convey the haptic sensation converted from the performer's motions.

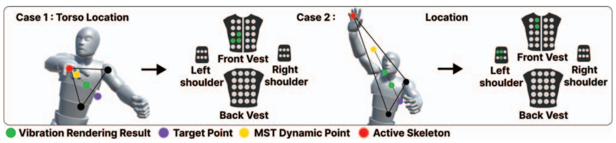

Figure 2: Two stationary points with Active Skeleton are forming **MST**. The actuators will vibrate when the raycast (staring from **MST Dynamic Point** to target point) hits the haptic display: vibration rendering results.

MST is a 3D triangulation, which the **MST Dynamic Point** is also located in 3D coordinate system. Translating its position to a 2D vibrotactile display eventually requires this system to project 3D coordinates to 2D coordinates. Therefore, we designate the *Target Point*, calculated from a centroid point of shoulder skeletons as well as the centroid points from each front and back torsos. Then we draw a ray-cast starting from **MST Dynamic Point** and ending with the *Target Point*. The point where the connected ray hits the haptic display will be the vibration rendering results. Regarding the raycast hitting the haptic display on continuous frames, it will consecutively vibrate with different actuators.

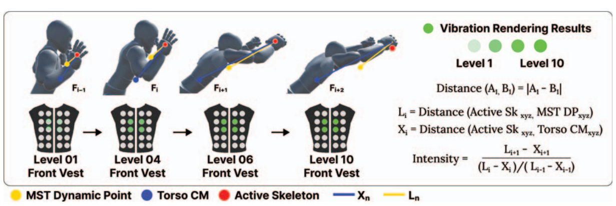

Figure 3: Translating distance to haptic intensity values: X_n indicates distance value of *Root Skeleton* and ***MST*** *dynamic point*, L_n indicates distance value of *Active Skeleton* and ***MST*** *dynamic point*.

In terms of translating vibrotactile feedback intensity, we compare the 3D moving distance between each frame rather than the 2D distance. This allows us to characterize distinctive haptic feedback when the target point only moves in the z-axis with the same 2D coordinate position. Therefore, as shown equations in the Figure 3: $Distance(A_1, B_1) = |A_1 - B_1|$, our pipeline compares each main point's 3D position increment or decrement amount when translating the haptic intensity level.

Referring to Figure 3, when the distance of **MST Dynamic Point** increases, the level of intensity linearly gets higher. Therefore, able to express the contrast intensity regarding the dynamic motion in the same x, and y-axis but different z-axis.

3 Preliminary Experiment

This work utilizes wearable vibrotactile suits and Tactosys equipment from bHaptics [1]. We chose pairs of Tactosys on both shoulder sides to feel more naturally rendered motion flow from the performer.

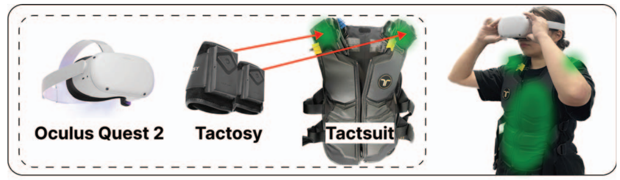

Figure 4: Our system consists of VR HMD, upper-body haptic suit, and Tactosys for shoulder placement to form an upper-body vibrotactile haptic system.

Following Figure 4 shows the overall image of how we attached the Tactosys to the shoulders above. Oculus Quest 2 is utilized for users to view virtual performance.

We recruited 5 participants whose average age is 23.8 years old (*SD=3.63*) and conducted a preliminary experiment. In the experiment, we chose two 15 s of discrete motions, with two different types of *choreography and highlight motion*. We required users to put on devices the same as Figure 4, and feel the vibrotactile haptic feedback, watching the performer's motions via HMD at the same time. Qualitative measurements were carried out, asking for Naturalness ("I was able to relate the wearable vibrations to the actions of the performers"), and Consistency ("I feel haptic feedback is well matching to the performer's motion(visual stimuli")).

Participants responded *"Overall vibrotactile stimuli represents the motion well detailed and sophisticated and realistic"*, asking for more various motions to experience. They also reported the importance of audio existence. Commenting *"It is interesting to feel the motion from others, however, regarding the concept of performance, it would be better to add the audio effects as well."*

4 Conclusion and Future Work

In this research, we propose a novel approach utilizing **MST**, translating the performer's motions to vibrotactile haptic sensation. As a preliminary of this system, we implement the variance of location and intensity from the 3D triangle (**MST**) to convey the motion flow. In the future, rules for distributing adaptive weight values regarding the motions need to be considered as well. Furthermore, as participants from the preliminary experiments mentioned the importance of the existence of audio, we plan to conduct user experiences combining motion and audio as input in parallel for rich vibrotactile feedback.

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