2025 IEEE World Haptics Conference (WHC)
Suwon Convention Center, Suwon, Korea
July 8 ~ 11, 2025

Assisting Safety for Visually Impaired Dancers with a Haptic Anklet

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I. Introduction

Visually impaired dancers, unlike sighted dancers, are unable to directly perceive their position on stage or nearby obstacles through visual perception. Ensuring the safety of them during performances is therefore of critical importance, necessitating strategies to prevent collisions and falls. Visually impaired individuals mainly rely on auditory or haptic feedback[1]. For dancers who need to follow music, auditory feedback is inappropriate. Haptic feedback, by contrast, allows unrestricted listening, avoids interference from noise, and enables rapid responses[2],[3].

Many studies have utilized haptic feedback to implement navigation and obstacle detection systems[4],[5]. However, these studies have mostly been conducted in static or slow-motion contexts, such as during everyday walking. It is important to note that dance is a highly dynamic activity. Recently, research has also begun to explore assistive devices for visually impaired individuals in dynamic environments. Muscle activation under dynamic conditions can affect the consistency of tactile feedback perception. One study using a device worn on the lower limb reported that variations in the force applied to the calf muscles influenced vibration sensitivity[6]. In the case of a vest-type assistive device for visually impaired soccer players, the effectiveness of the device has not been fully evaluated[7], and the design is unsuitable for dancers who require flexible upper body movements.

The ankle, due to its anatomical structure and sensory properties, is a favorable site for delivering vibratory tactile feedback. Its proximity to bone allows efficient transmission of vibration stimuli, and its structure, composed of distinct bones and tendons with dense innervation, is advantageous for providing localized feedback[8]. Moreover, the ankle permits free movement of the upper body and minimizes interference from muscle changes related to gait while delivering feedback. Additionally, since foot position is directly linked to overall body positioning, the ankle, being close to the foot, is highly suitable for providing effective and intuitive tactile feedback to prevent falls and collisions.

This study proposes a vibratory haptic anklet system to enhance the safety of visually impaired dancers in dynamic environments by preventing collisions with obstacles and maintaining spatial boundaries on stage, as illustrated in Fig.1.

II. System Description

The haptic anklet system is configured as shown in Fig.1.

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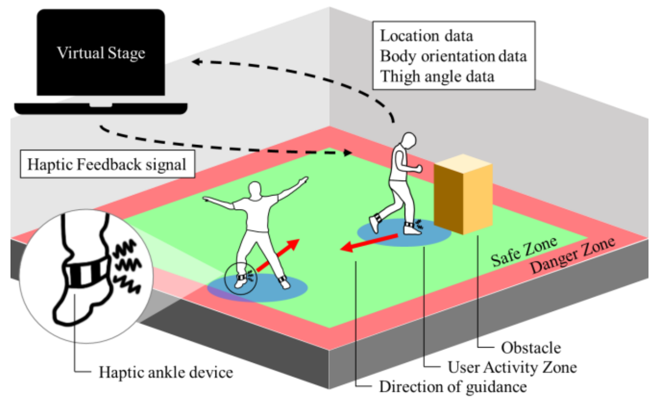

Figure 1. Schematic of the proposed system.

A. Danger Zone and User Activity Zone

The system enhances user safety by preventing falls and collisions through the definition of a *Danger Zone* and a *User Activity Zone*. An overlap between the two zones indicates a risk of falling or collision. The *User Activity Zone* is defined as an ellipse centered on the user's position, which is tracked using an optical tracking system. Its size is adjusted according to the user's movement speed, allowing earlier detection of hazards during faster movements.

B. Collision/Fall Direction Detection

To guide the user away from directions with a risk of falling or collision, the system calculates the direction of the detected Danger Zone. The collision direction relative to the user's orientation is computed as an angle and categorized into six sectors, each spaced 60 degrees apart.

C. Leading Foot Detection

The leading foot is inferred from the thigh angle, which is defined as the angle generated by the rotation of the thigh relative to the vertical axis of the ground. Although the thigh angle is closely related to the identification of the leading foot, it is difficult to determine whether the leading foot is the left or right foot based solely on a specific thigh angle. To address this, thigh angle data was collected using an IMU sensor, and a Long Short-Term Memory (LSTM) network was implemented to distinguish the leading foot. Considering the sequential nature of thigh angle changes during walking, an LSTM, which is suitable for processing time-series data among recurrent neural networks (RNNs), was employed. The model was trained using sequences of thigh angle data along with the corresponding actual leading foot labels, allowing the system to predict the leading foot based on input thigh angle values. Data were collected from six adult participants walking on a treadmill at speeds of 1, 2, 3, 4, and 5 km/h for approximately 30 seconds at each speed. The dataset was

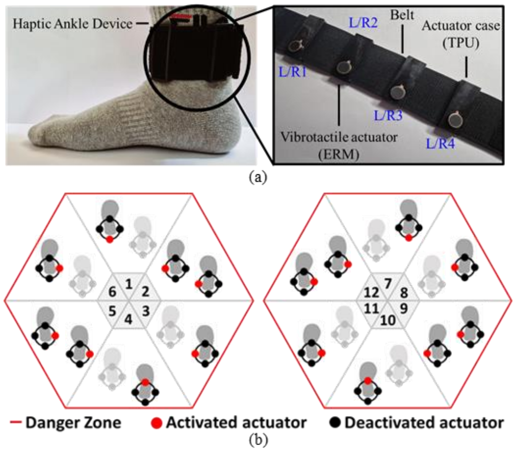

Figure 2. (a) Haptic Anklet (b) Haptic feedback signals based on danger zone location and the leading foot.

divided into training (80%) and testing (20%). The LSTM model achieved an accuracy of 94.25% in distinguishing whether the leading foot was the left or right foot.

D. Haptic Anklet

The haptic anklet of this system, as shown in Fig.2(a), consists of four ERM-type motors arranged around the ankle in a belt. The actuators are controlled by a microcontroller and are fixed inside TPU cases attached to a Velcro band. Wireless communication with the main PC is established via a Bluetooth module, and the system is powered by a lithium battery.

E. Haptic Feedback Design

As shown in Fig.2(b), haptic feedback is provided through four vibration actuators attached to each of the left and right ankles, with one actuator activated for guiding in the front, back, left, or right direction. Based on the leading foot and the location of the danger zone, feedback is delivered to the ankle of the foot closest to the danger zone. In cases where the closer foot is ambiguous, such as in Cases 2, 5, 9, and 12, feedback is provided to both ankles. The actuator positioned opposite to the direction of the danger zone is activated, and the system considers a total of 12 different scenarios.

III. Directional Perception

The proposed device delivers 10 types of haptic feedback, consisting of single motor activations at the front, back, left, and right of each ankle, as well as simultaneous left and right activations on both ankles, to guide foot movement and prevent falls or collisions. Perception tests were conducted under static and dynamic conditions to evaluate users' ability to recognize and differentiate these feedback signals.

A. Experimental Setup

A perception test was conducted with 10 participants (3 females, 7 males; mean age 25.17) under static and dynamic (2 km/h and 4 km/h walking) conditions. Participants, wearing haptic anklet, identified one of 10 feedback patterns while standing or walking on a treadmill. Responses were recorded via a tablet PC using a real-time GUI, with white noise played through headsets to ensure reliance on haptic feedback. Each pattern was presented randomly three times.

B. Experimental Result

The perception test results showed an overall average accuracy of 95.4%. Single-ankle feedback patterns achieved 90–100% accuracy, while dual-ankle feedback patterns achieved 86.7–90% accuracy. Average accuracy under static, 2 km/h, and 4 km/h conditions was 95.0%, 95.3%, and 96.0%, respectively(Fig.3).

4km/h		Response									
		↑		↓		←		→		⇇	⇉
		L	R	L	R	L	R	L	R	Both	Both
Actual	↑	0.97	1	0	0	0	0	0.03	0	0	0
	↓	0	0	1	1	0	0	0	0	0	0
	←	0	0	0	0.03	1	0.97	0	0	0	0
	→	0	0	0.03	0	0	0	0.93	1	0	0.03
	⇇	0	0	0	0	0.1	0	0	0	0.87	0.03
	⇉	0	0	0	0	0	0	0	0.1	0	0.9

Figure 3. Confusion matrix of experimental results at 4km/h.

IV. Conclusion

This study proposes a haptic anklet system that provides intuitive vibrotactile feedback to prevent falls and obstacle collisions for visually impaired dancers. This system uses the ankle's anatomical and sensory characteristics to deliver more accurate feedback to the ankle near fall and collision risk areas using four vibration motors. A directional perception test showed that users could accurately perceive the feedback, with an average 95.4% recognition accuracy. Further user testing will be conducted to confirm the system's effectiveness in real-world stage environments.

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