第 23 回日本バーチャルリアリティ学会大会論文集（2018 年 9 月）

StepSync：脚部スキル転移のための リアルタイムなウェアラブルシステム

StepSync: Wearable Skill Transfer System for Real-time Foot-Based Interaction

マーラナラザニ [1)]，ケイティーシーボン [2)]，檜山　敦 [2,3)], 稲見　昌彦 [2)]
Marla Narazani[1,2)]， Katie Seaborn[2)]， Atsushi Hiyama[2,3)]， Masahiko Inami[2)]

1) Department of Informatics, Technical University of Munich (Arcisstraße 21, 80333 Munich Germany, marla.narazani@tum.de）
2) Graduate School of Information Science and Technology, The University of Tokyo (〒113-0033 東京都文京区本郷 7-3-1, {kseaborn,hiyama,drinami}@star.rcast.u-tokyo.ac.jp）
3) Center for Advanced Intelligence Project, RIKEN (〒103-0027 東京都中央区日本橋 1-4-1)

Abstract: 本研究では、ダンス・体操などの足の運動に関する技能伝達の文脈において、視覚・触覚刺激を用いてインストラクターの運動を実時間で伝達する手法を提案する。靴に搭載した慣性センサによりインストラクターの運動を計測し、学習者の運動に視覚・触覚を通じて伝達するシステムを構築した。提案システムの評価として、触覚フィードフォワード提示と視覚フィードバック提示、またはその逆を行った場合について比較した。

Keywords: Interaction Design, Wearable computing, Skill transfer, Foot interaction

1. Introduction

Foot-based interactions facilitated by haptic and audio modalities have been widely explored in HCI, particularly to provide physical feedback based on virtual contexts in virtual and mixed reality applications [1][2]. However, there has been very little work on foot-based interaction in systems that involve the transfer of motor-based skills—skill-transfer systems—even where such interactions may be particularly appropriate. For example, skill transfer systems for running, dancing, or fitness—all of which involve, if not rely on, foot-based interaction—may be facilitated or enhanced by the use of a variety of interaction and information representation modalities, including and beyond the haptic, audio, and visual modalities. Even so, which modality or combination of modalities are most suitable may depend on the particular activity, actions, context, users, and other factors.

To investigate this, we created a new visual-haptic method for transferring foot movements from an instructor to a recipient in a real-time performance-oriented telexistence context. Following from this context, our method focuses on portability and non-intrusiveness. In such contexts, the ability to change one's location or orientation is very important; as such, users should not be bound to a specific location or orientation when performing. An ideal system is thus one that is able to move with the user or be attached to their clothing or footwear. Given this, we designed a wearable system consisting of a pair of smart shoes equipped with LED lights and haptic-enabled socks. The real-time skill transfer method itself consists of three stages. During the first stage, the instructor performs a foot movement that is captured using inertial measurement unit (IMU) sensors built into the shoes they are wearing. This movement is then interpreted in real-time as feedforward guidance and immediately transferred to the recipient, where it is displayed either in visual form using the LED lights on the shoes or as haptic vibrations through the actuators built into the socks. The recipient then attempts to perform the directed action, with feedback on accuracy presented through the opposite modality.

In this paper, we describe the design and technical setup of the proposed system and report on the results of an in-lab pilot study using two different configurations of the system.

2. Related Work

Foot-based interaction is a growing field of research, with much of the work involving comparisons to or reimagining hand-based interactions. Velloso *et al.* [3] found that feet interfaces can assist activities involving the use of the hands, but cannot replace them [3]. On the other hand, feet have been used as a way to digitalize classic foot interactions such as playing soccer on a mobile device [4] or eye-free shoe-based urban navigation [5].

Marla NARAZANI, Katie SEABORN, Atsushi HIYAMA, Masahiko INAMI

Figure 1: Left and central: The wearable prototype, including haptic-enabled socks and Orphe shoes with LED lights. Right: The expert-receiver system featuring the visual modality. From top to bottom: Wrong action (Mode 2), Right action (Mode 2), Move the left foot to the north (Mode 1).

In virtual and mixed reality, the growing interest in providing immersive experiences that involve all parts of the body has led to increased explorations of foot-based interactions [1][2]. In most studies so far, the feet are stimulated via haptic feedback according to presented scenarios. In most cases, a prototype augmented shoe equipped with pressure sensors, accelerometers, gyroscopes or similar motion or directional sensors has been used. Another similar application presented by Watanabe *et al.* [6] describes a shoe-shaped interface for unconsciously inducing a walking cycle by using haptic feedback. Similarly, Velloso *et al.* [3] suggest that foot-based input might best be realized through wearable computing since in such cases the user is able to move freely and interact spontaneously.

Light feedback as a form of visual feedback has been used as a way to quickly and simply provide information or notify the user about changes in the system [7][8][9]. These studies support the earlier work of Harrison *et al.* [13] who found that LED lights can convey more information than expected, allow for a richer output, and can be used as a way for devices to communicate their state. To the best of our knowledge, using light feedback in foot-based interaction has not yet been explored. Yet it may be used to supplement or work in place of haptic feedback in situations where vibrations and forces may be obscured or otherwise hard to detect, such as stomping or rapidly tapping on the ground during foot-based activities.

In the field of skill transfer for motor skills, there has been very little research that has explored the use of visual and haptic modalities, especially for foot-based skills. Yokokohji *et al.* [10] present one of the very first visual-haptic approaches to transferring skills from an expert to a trainee using a WYSIWYF (What You See Is What You Feel) display. Their main goal was the training of hand-based motors skills, such as surgical operations, handicrafts, or sports (such as tennis or golf). Another similar work, the "Virtual Teacher" by Gillespie *et al.* [11], used the metaphor of a teacher physically guiding the trainee's motion. In these examples, haptic feedback or feedforward plays a key role. Findings from a study by Feygin *et al.* [12] suggest that haptic guidance can benefit performance, especially when training the temporal aspects of a specific task. From this they conclude that haptic guidance could aid in training transfer.

3. System Design

To explore visual and haptic modalities as feedback and feedforward for telexistence skill-transfer, we built a portable, wearable system consisting of a proprietary smart shoe called Orphe[1] (developed by *no new folk studio*) equipped with LED light strips, a sock with built-in vibration motors, and a belt with a small bag carrying the required technical equipment (see Figure 1). The system allows an expert to send dance-style step-based instructions or guidance to a novice receiver in one of two modes: (i) visual feedforward and haptic feedback or (ii) haptic feedforward and visual feedback.

3.1 Hardware

Orphe has a built-in IMU sensor that provides real-time tracking of each foot for gesture detection. We extended Orphe by attaching a strip of 36 LED NeoPixel[2] lights to each shoe. Moreover, we created a haptic-enabled sock with four coin-style haptic actuators attached to each of the four cardinal points of the foot. Given the power requirements and weight, we created a belt that could hold the needed portable batteries, cables, and boards. To enable portable communication between components wirelessly, we used a Wi-Fi-enabled board, the ESP32.[3] The board can control the LED lights and the vibrations actuators upon receiving instructions from the software component.

[1] https://en.orphe.shoes/
[2] https://www.adafruit.com/category/168
[3] https://www.espressif.com/en/products/hardware/esp32/

3.2 Software

The main controller is an iOS application for macOS. It uses the Orphe framework for reading sensor data from the shoes. The framework, however, does not provide support for detecting additional gestures. For this reason, we had to implement our own foot gesture recognition system based on raw accelerometer data from the IMU. Since the main activity is dance-style step-based guidance, the detection of four gestures was required: STEP NORTH, STEP EAST, STEP SOUTH, STEP WEST. The accelerometer sensor data were partly filtered and then analyzed to find the specific pattern for a gesture. For STEP SOUTH, the STEP TOE gesture provided by the Orphe framework was also used. Since users have to move their feet to perform a gesture and then move their feet back to their initial position, there is a specific timeframe within which gestures are not analyzed after the last performed movement. Moreover, the game controller checks if the recipient is performing the gestures correctly, i.e., if they are performing the correct gestures within the given timeframe. The board is controlled with three different types of requests: change mode (light for instructions and vibration for feedback, and vice versa), send instructions, and send feedback.

3.3 Communication

The smart shoes communicate with the game controller via Bluetooth using the Open Sound Control (OSC) protocol. The game controller communicates with the board via Wi-Fi; the board runs a web server during the experiment and listens for incoming requests from clients. Upon gesture detection, a request is sent from the controller to the board indicating: the side of the shoe (left or right), direction (N, E, S, W) and feedback if the gesture was performed correctly (YES/NO).

4. Experiment

We conducted a within-subjects, in-lab pilot study with five healthy participants aged between 20 and 40 (4 men, 1 woman); see Figure 2 for an illustration of the setting. The experiment required two participants: the expert and the recipient. The first author acted in the role of the expert to ensure experimental control (i.e., activity expertise). Participants were given initial instructions on how to perform the foot gestures and were informed about the two modes of the experiment.

4.1 Procedure

The participant was directed to perform several foot gestures while being physically separated from the expert using a room divider. Each could see each the other during the activity. On one side of the room divider was the expert, wearing a pair of Orphe shoes and using headphones. The recipient was on the other side, wearing the extended version of Orphe and the rest of the equipment, as well as headphones. Both were video recorded during the activity. Given the delay between the expert and the recipient when performing gestures, and in order to ensure music synchronization of both players, the music of the recipient started with a minor delay (800 ms).

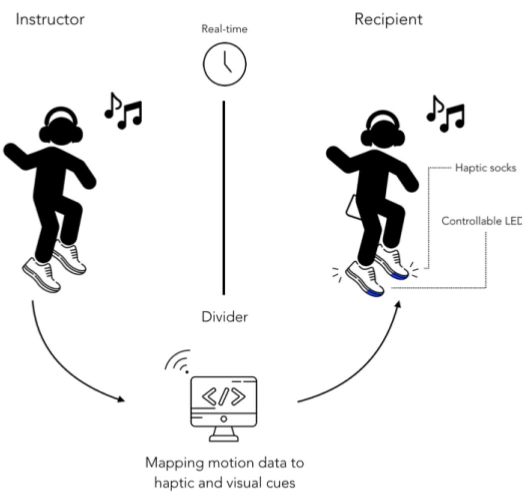

Figure 2: The experimental setting.

The sequence of gestures performed by the expert played a key role in the experiment. Since our goal was to ensure that there were no predefined instructions for the expert—allowing for spontaneous actions, as befitting a dance context—we used a similar paradigm to the Virtual Teacher [11] and let the software take the role of the teacher for giving feedback. We used a simple correction method: an incorrect move on the part of the recipient was defined as either ‘the wrong gesture was performed’ or ‘the gesture was correct, but they were not quick enough’. These are described in detail in 4.2.

The aims of the experiment were to assess the portability of the wearable system and gather insights into the thoughts of the participant regarding the selected modalities. As such, a 9-item questionnaire was created around these concerns and given to each participant after they experienced both conditions.

4.2 Conditions: Gestures and Modes

The experiment involved testing two modes: visual feedforward and haptic feedback, and vice versa. The first mode used the LED lights for instructions and vibration for feedback. In this mode, vibration of all actuators indicated a wrong execution of the gesture by the recipient. No vibration, on the other hand, indicated a correct execution. In the second mode, the modalities were switched. Vibration was used for instructions and the LED lights for feedback. In case of a correct execution, all LED lights flashed green, and in case of a wrong execution, they flashed red.

5. Results and Discussion

Most participants (4/5) described the vibration instructions as being moderately difficult while opinions about the visual mode varied. Yet there was not a clear preference for one modality either for instructions or feedback. There was a slight preference for the vibration modality, but the sample size is too low to be certain. Participants also preferred combinations of modalities (e.g., visual feedback and haptic feedforward) rather than one modality for both kinds of information; however, this may have been due to having experienced this as part of the experiment.

One concern going into this research was that participants would not look at the visual feedback due to it not being crucial for the performance. Yet the majority (4/5) did pay attention to the light feedback. This gives confidence going forward with such a system in place of the more common approach of using vibration feedback. Users pointed out that when using the built-in LEDs, they were unable to detect the SOUTH instructions, particularly because the lights reflected off the inside of each shoe. This can be remedied by changing the material on the shoe to a non-reflective version. Regarding vibration, two users found that it was difficult to differentiate between the directions. It is hard to determine which caused the most difficulty, but a user study where each is slightly repositioned and tested could reveal the difficulties.

Most users felt that the experience was fun, but they also did not feel in sync with the music. The reason behind this could have been the delay (800ms) set before the experiment, which could be refined with further testing. Even though most participants felt that they did not dance properly, most also reported that they felt immersed during the performance. This suggests that either the dance moves were too restrictive or that such a system may be better suited to non-music-based foot-interaction.

6. Conclusions and Future Work

In this paper we presented a wearable system for real-time skill transfer in a foot-based context. We designed our system to provide real-time instructions and feedback based on visual and haptic cues. Our findings suggest that there is no clear preference for one mode; a combination of both modalities for feedback and feedforward may be best. Users were able to feel immersed and had a pleasant experience in a limited setting, one without displays and with all interactions provided by the wearable technology. Findings suggest non-dance contexts may also be appropriate, which future work can explore.

7. Acknowledgements

This research is partially supported by JSPS International Fellowships for Research in Japan, and JST CREST(JPMJCR16E1).

References

[1] Turchet, Luca, Paolo Burelli, and Stefania Serafin. "Haptic feedback for enhancing realism of walking simulations." *IEEE transactions on haptics* 6.1 (2013)

[2] Kruijff, Ernst, et al. "On your feet!: Enhancing vection in leaning-based interfaces through multisensory stimuli." *Proceedings of the 2016 Symposium on Spatial User Interaction*. ACM, 2016.

[3] Velloso, Eduardo and Dominik Schmidt. “The Feet in HCI : A Survey of Foot-Based Interaction.”. 2015.

[4] Plantevin, Valère, and Bob-Antoine J. Menelas. "Use of ecological gestures in soccer games running on mobile devices." *Int. J. Serious Games* 1.4 (2014): 49-60.

[5] Schirmer, Maximilian, et al. "Shoe me the way: a shoe-based tactile interface for eyes-free urban navigation." *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, 2015.

[6] Watanabe, Junji, Hideyuki Ando, and Taro Maeda. "Shoe-shaped interface for inducing a walking cycle." *Proceedings of the 2005 international conference on Augmented tele-existence*. ACM, 2005.

[7] Freeman, Euan, Stephen Brewster, and Vuokko Lantz. "Interactive Light Feedback: Illuminating Above-Device Gesture Interfaces." *Human-Computer Interaction*. Springer, Cham, 2015.

[8] Arif, Ahmed Sabbir, et al. "Extending the Design Space of Tangible Objects via Low-Resolution Edge Displays." *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, 2017.

[9] Pohl, Henning, Justyna Medrek, and Michael Rohs. "ScatterWatch: subtle notifications via indirect illumination scattered in the skin." *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, 2016.

[10] Yokokohji, Yasuyoshi, et al. "Toward machine mediated training of motor skills. Skill transfer from human to human via virtual environment." *Robot and Human Communication, 1996., 5th IEEE International Workshop on*. IEEE, 1996.

[11] Gillespie, R. Brent, et al. "The virtual teacher." *Proceedings of the ASME Dynamic Systems and Control Division*. Vol. 64. American Society of Mechanical Engineers, 1998.

[12] Feygin, David, Madeleine Keehner, and R. Tendick. "Haptic guidance: Experimental evaluation of a haptic training method for a perceptual motor skill." *Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2002. HAPTICS 2002. Proceedings. 10th Symposium on*. IEEE, 2002.

[13] Harrison, Chris, et al. "Unlocking the expressivity of point lights." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2012.