Got rhythm? Haptic-only lead and follow dancing

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Abstract. This paper describes the deign and implementation of a lead and follow dance to be performed with a human follower and PHANToM leader, or executed by two humans via two PHANToMs reciprocally linked. In some contexts, such as teaching calligraphic character writing, haptic-only communication of information has demonstrated limited effectiveness. This project was inspired by the observation that experienced partner dance followers can easily decipher haptic-only cues, perhaps because of the structure of dancing, wherein a set of possible moves is known and changes between moves happen at times signaled by the music. This work is a demonstration of dancing, meaning coordination of a randomly sequenced set of known movements to a musical soundtrack, with a PHANToM as a leader, and of a human leader and follower dancing via a dual PHANToM teleoperation system.

1 Background

In numerous studies, human haptic and proprioceptive senses have been shown to lack the precision of visual perception. For example, just noticeable differences (JND's) for force perception are larger than those for visual perception [1]. Previous work on haptic interfaces between humans found evidence that haptic-only cooperation was inferior to visual-only cooperation and found no evidence that haptic-plus-visual cooperation was superior to visual-only cooperation when the item to be communicated was an unknown Japanese calligraphic character [2]. However, experienced swing dance followers have demonstrated in our lab the ability to correctly identify moves while deprived by blindfold of visual information. The distinction between these tasks is likely the highly structured nature of swing dance. In social improvised swing dance, the leader choreographs for himself and his follower in real-time. All swing dancers know a set of stereotypical eight-count moves. The leader, then, needs only to communicate the selection of move from this finite alphabet, not the requested trajectory in its full detail. To demonstrate haptic-only communication in a simpler setting than that of full-body motion, we designed a dance to be performed with one hand and arm using a PHANToM haptic device from Sensable Technologies. We implemented a leader-follower dance to be executed between a human and a PHANToM device, or between two humans mediated by two PHANToM devices. The primary goal is to investigate human-human and computer-human interaction strategies in the specific context of improvised dance, hence the system was designed to be faithful to the dancing model even at the risk of less transparent results.

Other examples of haptic motion coordination between robots and humans include a walking robot that can follow a person who takes its hand to lead it [robotfollow-human], and Hale's "sticky hands" tai chi demonstration between an anthropomorphic robot and a human [hale00]. In the latter, the human and robot did not have clearly defined roles as leader and follower, but the robot learned and categorized the human's movement patterns in order to generate movements.

2 Dancing PHANToM System

A PHANToM is a programmable 3-D haptic device which presents a force at its stylus endpoint that is a function of its sensed position. Because a PHANToM has only a single point of contact with the user, a simple data trace results from each execution. The PHANToM's behavior as a leader is reproducible across experiments, whereas no human leader's performance could be.

2.1 Single-user System

The PHANToM generates forces and reports its position and velocity at 1000 Hz. The target point p_t moves along a path parameterized by t , $(75\cos(\pm\pi t), 75\sin(\pm\pi t), 0)$, and so the target velocity v_t is $(-75\pi\sin(\pm\pi t), 75\pi\cos(\pm\pi t), 0)$. The x, y, z coordinates of the PHANToM's point of contact and the force exerted are captured. Here, the x direction is the user's left-right, y is the user's down-up, and z is the user's away-toward when the user is seated at a PHANToM on a desk.

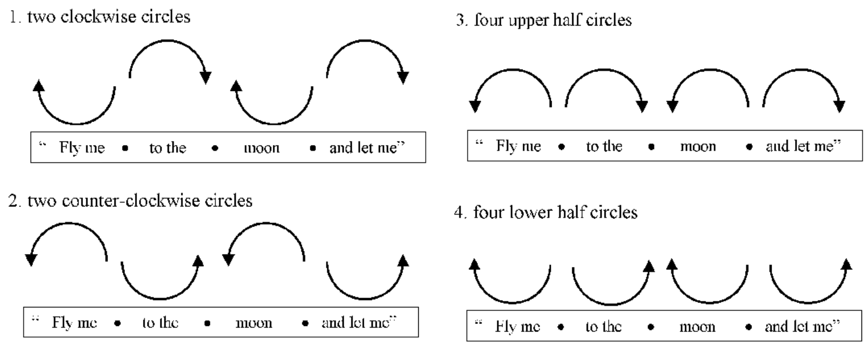

Fig. 1. dance moves

The haptic dance, like many dance forms, has syntactic content. Moves are selected from a set of four moves: two clockwise circles, two counterclockwise circles, four upper half circles (with three direction reversals), and four lower half circles, all in the x, y plane. The moves are illustrated in Figure 1.

The PHANToM leads a human follower in unknown sequences of known moves to a MIDI soundtrack of a well-known song. In preliminary versions of the system, a MIDI drumbeat call was placed within the PHANToM servo loop code. Empirically, this sound call needed to occur about 50 ms after the target reversed direction, as in pattern 3, to be perceived as synchronized with the direction reversal. The same required delay was incorporated as the start time of the soundtrack.

The PHANToM acts as a modified proportional-derivative feedback controller to lead the human user. The force imposed, F, is a function of the position and velocity of the stylus, p_s and v_s, and the target position p_t and velocity v_t. Consider the error in the pattern plane,

$$e_p = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} (p_t - p_s), e_v = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} (v_t - v_s)$$

and separately in the *z* direction,

$$e_z = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} (p_t - p_{s})$$

The force fed back to the user is

$$F = k_z e_z + (1 + k_g \|e_z\|)(k_p e_p + k_v e_v) \quad (1)$$

The first term enforces a preferred plane for the moves, and the second term is the PD feedback, with gains increasing with distance from the preferred plane. Increasing gains with distance from the preferred plane by factor k_g was intended to mimic the feel of increasing tension with distance from a partner in dancing. However, subjects did not utilize this feature by pulling the PHANToM out of the preferred plane. The constants used were k_p = 0.0034 N/mm k_v = 0.0017 N-s/mm, k_z = 0.03 N/mm, and k_g = 0.01 N/mm. Feygin et al. used a similar PD controller to train subjects in a 3-D gesture task [5].

It is crucial to note that although the PHANToM leader is implemented as a position and velocity controller, the human follower holding the stylus is not constrained to move as the target does. The subject must actively move his hand and arm to follow the dance. This is due to the small gains k_p and k_v. Larger gains would not be implementable using this device, and would not be desirable in that they would not permit soft interaction. Soft interaction means that the user is presented with a haptic error signal but not physically forced through the motions; soft interaction is realized in partner dancing.

2.2 Two User System

With two PHANToMs installed on a single computer, two users can interact in a traceable way. The follower is presented with a PHANToM that acts as it did in the single user game, except that the target position and velocity for the follower is the position and velocity of the leader's device arm. The leader's device could also exert forces tracking the position and velocity of the follower's PHANToM, or alternately the communication might be one way only.

3 Experiments

3.1 Protocol

Six volunteer subjects familiar with the PHANToM were instructed to try to follow the PHANToM's lead. They were told that the dance was synchronized with the music and consisted of four simple moves. The subjects could see their hand while using the system, but no display of the desired pattern was given. The subjects first trained for 60 seconds each on the four moves from figure 1. The subjects then trained for 90 seconds each on four two-move fixed sequences, such as two clockwise circles followed by four lower half circles. The subjects were informed what the pattern of moves was for each training session. The subjects then followed six randomly generated move sequences lasting 120 seconds. Participants expressed varying levels of entertainment and frustration in trying to follow the moves.

3.2 Results

3.2.1 Single User

Figure 2 shows a typical human-PHANToM system trajectory for a sequence of about eight seconds, where the solid line is actual position. Note the vertical and slighter horizontal offset of the executed pattern from the target. Because the feedback gain for the position was relatively small compared to that for velocity (in [5] k_p was about 200 times larger than k_v , where here k_p is only twice as large as k_v , detecting these position offsets was difficult for subjects. Because force exerted by the PHANToM was the only display of error, force tracking is a more reasonable performance measure.

Figure 3 shows PHANToM force output in the y direction, averaged over four subjects and over ten instances each, during the 90 second practice sessions that repeated series of two moves. During these practice sessions, then, all of the moves and transitions should have been anticipated. It does appear that prior to direction reversals, subjects move in ways that modulate the force in the opposite direction to the imminent change.

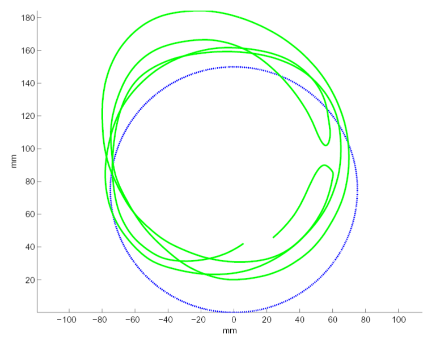

Fig. 2. Position and target, *x* versus *y*

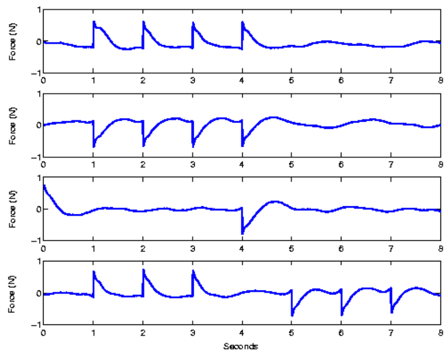

Fig. 3. *y* forces, practice, moves: 3 then 2, 4 then 1, 2 then 1, 3 then 4. See Figure 1.

In examining phase diagrams of human response versus target motion, it is clear that the sharp turnarounds of the target track are not physically plausible for subjects. The target velocity has a step change from π rad/s to - π rad/s, but the arm had too much inertia to mimic that reversal.

One goal of this work was to demonstrate that foreknowledge of or recognition of, say, pattern 1, resulted in improved performance but misclassification of a move resulted in reduced performance. Examples of a desired response and an obvious misclassification in this experiment's data are shown in figures 4 and 5, where the desired response was to reverse the half circle at the left side of the figure. Judges could hand-score these transitions, or an objective measure such as delay before direction reversal could be employed to identify misclassifications of moves in this data.

3.2.2 Two User

A subject familiar with both leading social dance and playing the follower role in the single user haptic dance lead another subject who had played the follower role in the single user haptic dance. The two subjects could not see each other, but were in the same room hearing the same soundtrack. The leader choreographed spontaneous routines while the follower followed. This part of the study compared the target point motion near move transitions as generated by a human leader to that used by the automated leader for the single user dance.

In the dual PHANToM setup, the human leader exhibited smooth velocity profiles as expected. This difference between the PHANToM's lead and a human's lead did not adversely affect the follower's performance. In further experiments, all moves will have smooth velocity profiles.

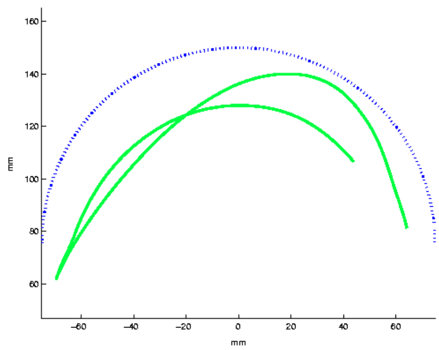

Fig. 2. desired reversal

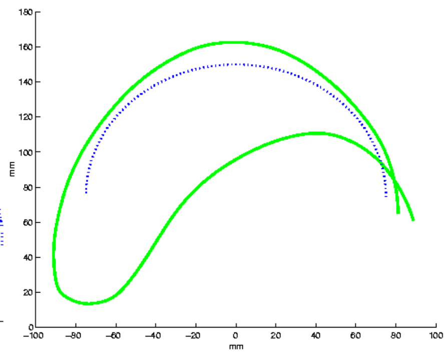

Fig. 3. anticipated no reversal, mistakenly

Experiments were conducted with one way and two way or peer connection between the leader and follower PHANToMs. In practice the leaders felt that the feedback from the followers was distracting, and that the experience was more satisfying with only one way communication. This preference suggests that the position and velocity tracking implemented create an impression dissimilar to actual contact with another human. Solving this problem is an aim of future versions.

4 Conclusions and Future Work

This paper described a haptic lead and follow dance, with auditory cues (soundtrack) but no visual display, implemented using a PHANToM. Partner dancing is a quintessentially haptic experience, and investigating the form of communication links between humans in dance could point the way to more natural human-computer interaction. This demonstration implements a simplified dance that can function as a setting for asking questions about physiological delays, the usefulness of rhythm cues for movement, the function of a movement vocabulary in coordinating movements between actors, and more.

With a revised set of moves, experiments will be conducted that aim to demonstrate subject competence at inferring and performing the correct move when the moves are randomly sequenced, even in this haptic-only communication setting. Improved telepresence for human-human interaction, for example in distance training applications [japcallig], may require an understanding of modalities of leading and following.

5 Acknowledgements

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