LightGuide: Projected Visualizations for Hand Movement Guidance

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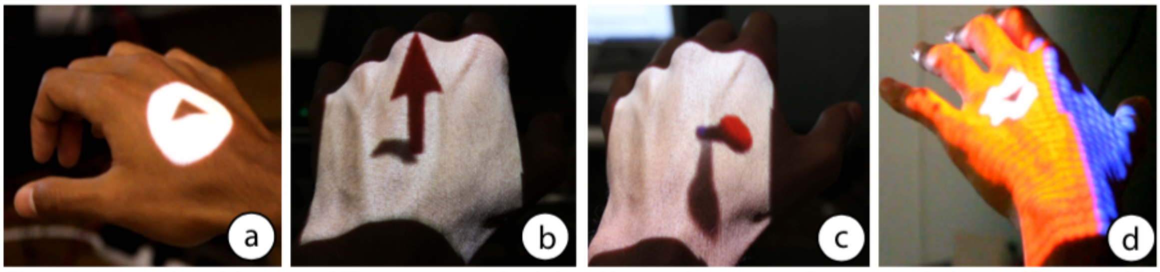

Figure 1. An overview of the range of 3D cues we created to help guide a user's movement. In (a), a user is shown a 2D arrow with a circle that moves in the horizontal plane, (b) shows a 3D arrow, (c) a 3D path where blue indicates the movement trajectory and (d) uses positive and negative spatial coloring with an arrow on the user's hand to indicate depth.

ABSTRACT

LightGuide is a system that explores a new approach to gesture guidance where we project guidance hints directly on a user's body. These projected hints guide the user in completing the desired motion with their body part which is particularly useful for performing movements that require accuracy and proper technique, such as during exercise or physical therapy. Our proof-of-concept implementation consists of a single low-cost depth camera and projector and we present four novel interaction techniques that are focused on guiding a user's hand in mid-air. Our visualizations are designed to incorporate both feedback and feedforward cues to help guide users through a range of movements. We quantify the performance of *LightGuide* in a user study comparing each of our on-body visualizations to hand animation videos on a computer display in both time and accuracy. Exceeding our expectations, participants performed movements with an average error of 21.6mm, nearly 85% more accurately than when guided by video.

Author Keywords

On-demand interfaces; on-body computing; appropriated surfaces; tracking; spatial augmented reality;

USER STUDY

The purpose of this study was to demonstrate the feasibility of our approach and to determine if our prototype is capable of guiding a user's hand in mid-air. Specifically, we wanted to know how accurately users follow on-body projected visualizations. We also wanted to investigate how the accuracy and behavior of a user changes for paths at varying depth levels. In addition to following, we also explored the accuracy and speed of self-guided movements where users dictate their own pace of a movement.

To place LightGuide's performance in context, we compared our method to video as we felt it was representative of a resource that users currently utilize. The *video condition*, shown in Figure 8, is comprised of a 3D

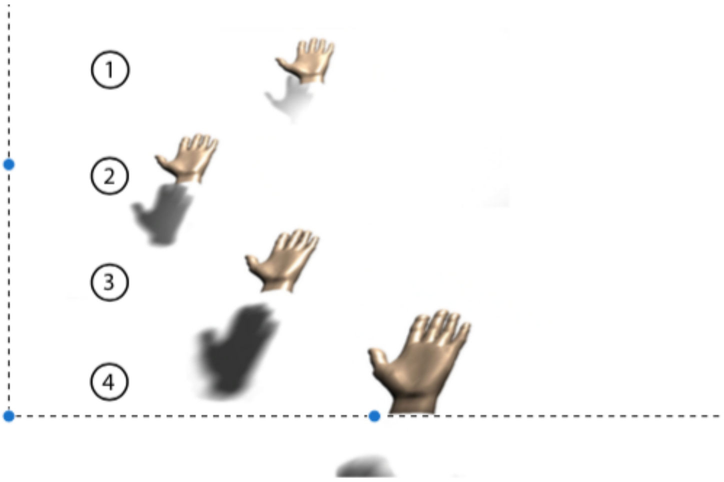

Figure 8. A rendering of the 3D hand that is used in our video condition. The motion is an arc that moves towards the user and gradually increases in depth.

model of hand that follows an ideal, system-generated path. Although our animated video does not provide nearly as much visual context to participants as a real life video, a system controllable video allowed us to remove the effects of any human or tracking error that could affect the movement paths. More importantly, the animated video allowed us to control the perspective of the video (e.g. rendered from the user's perspective) as well as precisely control the speed and timing of replayed movements. While we feel that the best performance with our system can be attained by using both video and on-body hints, our comparison independently measures the effect of our visual hints and video for movement guidance.

Participants

We recruited 10 right-handed participants from our local metropolitan area (2 female) ranging in age from 18 to 40. All participants were screened prior to the study to ensure their range of motion was adequate to perform our tasks. The study took approximately 90 minutes and participants received a gratuity for their time.

Test Movements

Our goal was to support interactions on a variety of movements. For our user study, we included five different paths: a line which must be traced back and forth, a square, a circle, an 'N', and a line plus a curve (Figure 9). These paths share similar characteristics to the types of movements patients are asked to perform in physical therapy sessions (see Motivation). The paths, seen in Figure 9, range in length from 300 to 630mm (mean = 438.1 mm, SD = 130.6mm). To ensure that we adequately tested a variety of depth levels, we vary the paths at three different angles: 0°, 45° and 90° with respect to the horizontal plane in the participant's frame of reference.

Procedure

During the experiment, participants were instructed to stand at a comfortable position underneath the overhead projector and depth-sensing camera. Prior to starting, we verified that

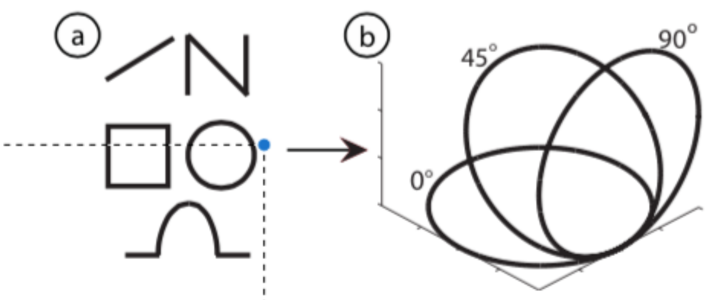

Figure 9. In (a) the test paths used in our study, (b) each path is oriented at 0°, 45° and 90° (only a circle path is shown).

each participant had enough room to move their hand while being adequately tracked by the system.

The primary task consisted of a participant moving their hand in space following specific hand guidance visual hints. By 'following', we mean that a visual hint would begin moving in space at a speed of 30 mm/sec. and participants would follow the hint and respond to its cues. Our choice of 30mm/sec for visualization speed was chosen through informal pilot studies that had users try out a variety of speeds. 30 mm/sec was chosen to be the most comfortable constant speed while still producing reasonable hand motions. To quantify how users perform a movement at their own pace, a secondary task was included where the same *3D Arrow* was used without any system imposed timing. That is, the *3D Arrow* would only change position if the user responded to the direction indicated by the *3D Arrow*. We refer to this as *self-guided.*

We performed a within subjects experiment and in total, we tested 6 visual hints: *Follow Spot, 3D Follow-Arrow, 3D Self-Guided Arrow, 3D Pathlet, Video on Hand,* and *Video on Screen.* Here on, we refer to our two *3D Arrow* conditions as *3D F-Arrow* and *3D SG-Arrow.* All except the *Video on Screen* condition were projected on the participant's hand. Our baseline *Video on Screen* condition was shown to a participant on a computer monitor situated directly in front of the user. Importantly, participants were told to keep their hands flat (facing down) during the entire experiment to ensure that the visual hints would consistently appear on their hands between trials as well as to ensure consistent hand tracking performance by our system.

To provide consistent start location for each movement, we marked the desired starting hand location with markers on the floor in front of the participant and asked them to return to the marker before beginning each new trial. In each trial, participants were instructed to hold out their hand and follow the guidance cues completing a single path as accurately as possible. We asked the participant to keep the visual hint at the center of their hand. Once the path was completed, the system would sound a 'chime' and a red circle would appear on the participant's hand signaling the user to return to the start position. In total, participants were asked to follow a single visualization over our 15 test paths; presentation order was randomized. The procedure was repeated for each of our conditions.

Before each measurement phase, participants were allowed to practice using the visual hints to move through a path. Each condition lasted approximately 10 minutes, of which 5 minutes was used for practice and 5 minutes for measurement. Between conditions, we allocated 5 minutes for participants to rest in order to reduce the effects of hand fatigue.

Each session produced 90 trials (6 conditions x 5 paths x 3 angles) per participant. To counter-balance the conditions, the presentation of each condition was randomized to remove the effects of ordering. Users were interviewed after each session followed by a short post-study interview. We recorded video of the participants and measured their position, hand-orientation and time.

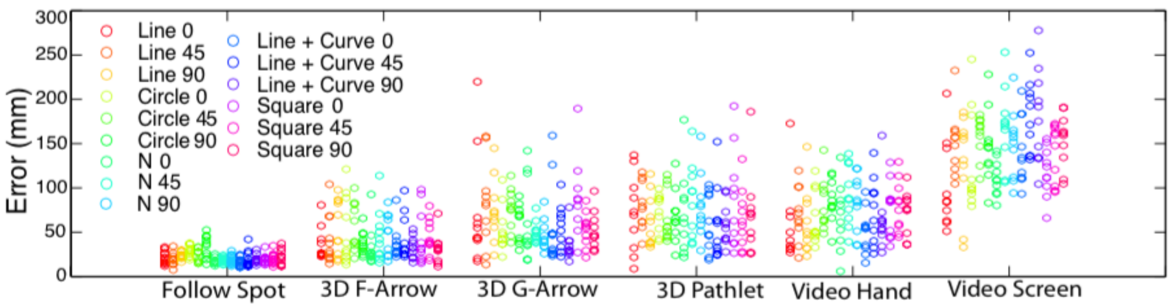

Figure 10. Overall distribution of unscaled deviations from a path. The circles denote users while colors show the 15 unique paths.