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Head tracking performance: the use of a 'look-ahead trace' to control target motion predictability

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ABSTRACT

A method of varying the predictability of the position of a randomly moving circular target is proposed and evaluated. This method presents the present position of a target as a circle and the next few target positions as a trace (referred to as a 'look-ahead trace'). Dual-axis head tracking performance with a 'look-ahead trace' was studied. Targets were presented using a head-coupled virtual reality system consisting of a head tracker and a helmet-mounted display. Eight subjects participated in the study. Results showed that with 'look-ahead traces' showing targets up to 560 ms ahead (referred to as the 'trace duration'), the phase lags of the head tracking transfer functions decreased with increasing trace duration. This indicates that the subjects were able to follow the moving circular target better with the help of a 'look-ahead trace'. The subjective difficulty ratings and the tracking errors also decreased with increasing trace duration.

RELEVANCE TO INDUSTRY

Tracking performance with a simple symmetrical target (e.g. circle) is frequently reported and results have been used to predict tracking performance with tasks in which the target shape provides a cue to the direction of target movement. This paper highlights a problem with the use of symmetrical targets and shows an improvement in tracking performance when there are additional cues to the direction of travel of the target.

Keywords: Head tracking; Target motion predictability; Helmet-mounted display; Virtual reality

1.0 INTRODUCTION

1.1 Head tracking performance

Knowledge on visual-motor response in humans is essential for the optimum design of control and display instruments (Boff and Lincoln, 1988). With recent advances in head-coupled immersive virtual reality systems, head-controlled displays and devices are being developed (e.g. head-steered guns: Williams, 1987; virtual reality simulators: Geltmacher, 1988). In order to optimize the design of head-steered devices, head tracking responses will need to be studied and understood (So and Griffin, 1995).

1.2 A problem with the use of a circular targets

A typical study of head tracking performance involves the visual presentation of a target and the recording of the head movement response to that target. Similar to studies of manual tracking performance (e.g. Krendel and MuRuer, 1960; McRuer, 1973), circular targets have been used in dual-axis head tracking studies (e.g. So and Griffin, 1995). This may lead to problems as a circular target does not convey as much information as some real targets. Targets in many real tracking tasks have well-defined front and rear parts and they move along the pointing directions of their front parts. A circular target, on the other hand, does not have a front or rear part and so its direction of movement can be random. This paper presents a study investigating head tracking strategy with a moving circular target giving cues to its direction of movement.

1.3 Additional cueing with a 'look-ahead trace'

To increase the predictability of a randomly moving circular target, future target positions can be shown in advance to the subjects in the form of a trace (Figure 1). The length of the trace (referred to as 'look-ahead trace') is determined by the maximum lead time of the future target positions. Tracking with this 'look-ahead trace' is analogous to driving at night where the headlights enable a driver to see part of the road ahead. The power of the light beam determines how far ahead the driver can see.

2.0 METHOD

2.1 Objectives and hypotheses

Two experiments were conducted to investigate (i) the effects of learning with a 'look-ahead trace' and (ii) the effects of 'look-ahead trace' on head tracking performance. It was hypothesized that: (i) the effects of repeated-tracking (i.e. practices) with a 'look-ahead trace' will be small since head tracking with a semi-predictable target motion is very common; (ii) the use of a 'look-ahead trace' will reduce the perceived task difficulty; and (iii) the use of a 'look-ahead trace' will reduce the head tracking phase lag.

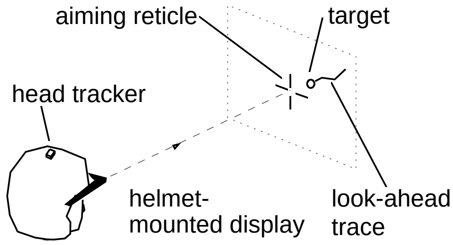

Figure 1. Subject's view of a target with a 'look-ahead trace'.

2.2 Tasks, subjects, and design of experiment

During each tracking condition, subjects were asked to move their heads to track a circular target moving randomly in the pitch and the yaw axes for 120 seconds. The yaw axis target motion was a random function integrated once, high-pass filtered at 0.01 Hz (24 dB/octave), and low-pass filtered at 1.2 Hz (120 dB/octave). The pitch axis target motion was the same as that of the yaw axis but was presented in reverse order. Eight similar but different target motions were used to balance the sequence of presentation of the conditions. An 8 x 8 Latin square design was used. These eight target motions all had the same frequency content.

The first experiment investigated the effects of practice. The subjects repeated the tracking task eight times, first without a 'look-ahead trace' and then with a 'look-ahead trace' showing target positions up to 160 ms ahead. This experiment also provided training for the subjects. In the second experiment, 'look-ahead traces' showing targets with up to eight different lead times were presented (0, 80, 160, 240, 330, 400, 480, 560 ms). Eight healthy male subjects participated in both experiments. They were either university students or researchers and their ages ranged from 19 to 26.

2.3 Apparatus

The dual-axis tracking task was presented on an experimental head-coupled virtual reality system. The system consisted of a Hughes Aircraft monocular helmet-mounted display with 17° x 17° field-of-view, a Ferranti SPASYN magnetic head tracking system; and a host computer workstation.

2.4 Measurements and analyses

A quasi-linear model of the head tracking system is shown in Figure 2. Head positions in response to the target motions were measured (point B, Figure 2) and expressed as head tracking transfer functions. The moduli and phases of such transfer functions were used as indicators of the tracking responses. The head tracking transfer functions are defined as follows:

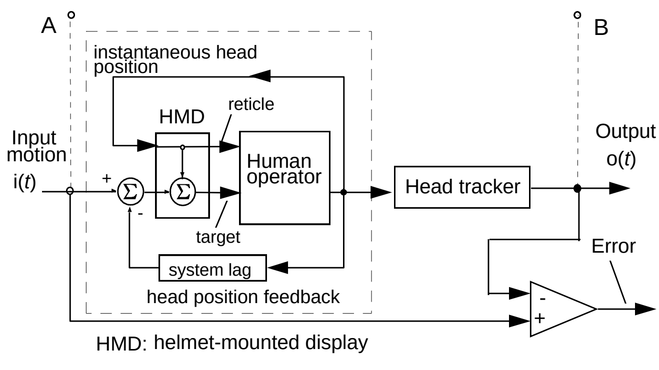

Figure 2. A quasi-linear model of the head tracking system.

Head tracking transfer functions = [$G_{oi}(f)$ / $G_{ii}(f)$], where $G_{oi}(f)$ is the cross-spectral density between the measured head position (o(t) at point B, Figure 2), and the input target position (i(t) at point A, Figure 2); and $G_{ii}(f)$ is the power spectral density of i(t).

Radial tracking errors and subjective difficulty ratings were also measured. A six-point (0-5) absolute difficulty rating scale was used: this scale has been used in previous studies on head tracking performance (e.g. So and Griffin, 1992). The radial tracking errors were calculated as follows:

Radial tracking error = $\{\sum \sqrt{[x^2(t) + y^2(t)]}\}$, where x($t$) and y($t$) are the instantaneous head tracking errors (in degrees) in the yaw and pitch axes respectively.

3.0 RESULTS AND DISCUSSION

3.1 Repeated-run

Head tracking transfer functions for the 8 repeated-runs are shown for the yaw axis in Figure 3. With and without the use of a 'look-ahead trace', a trend can be observed for the moduli (i.e. tracking gains) to decrease with increasing practice. However, the effects were not statistically significant (p>0.05: without trace; p>0.02: with trace, at 0.94 Hz, Friedman two-way analyses of variance by ranks). The phase lag responses of the transfer functions increased slightly with practice although the effects were also not significant (p>0.1: without 'trace'; p>0.02: with 'trace'; 0.94Hz, Friedman). Results from the pitch axis were similar.

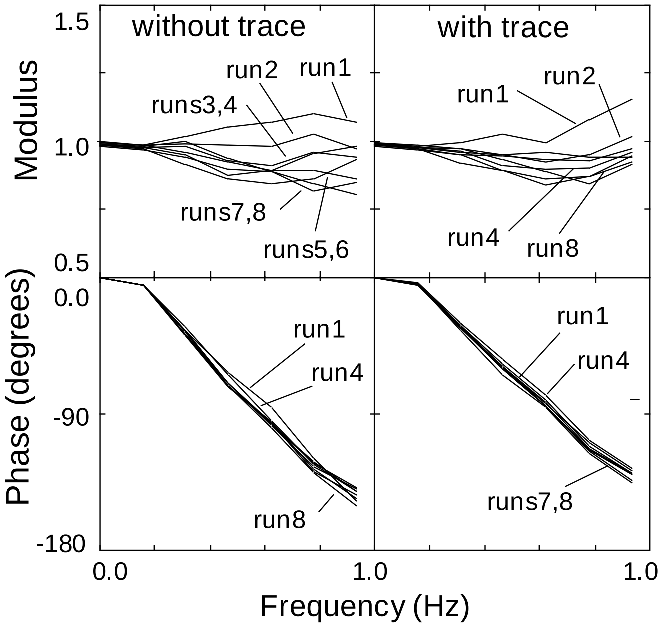

Figure 3. Yaw axis head tracking transfer functions obtained in 8 repeated-runs; with and without a 160ms 'look-ahead trace' (mean of 8 subjects' data).

3.2 'Look-ahead trace'

Head tracking transfer functions with 'look-ahead traces' of different trace durations are shown in Figure 4. The reductions in phase lag at 0.94 Hz related to the condition with a 'look-ahead trace' are shown in Figure 5. The results indicate that as the trace duration increased, the head tracking phase lag decreased (p<0.001 at 0.5 Hz; p<0.001 at 0.94 Hz; Friedman two-way analyses of variance by ranks). This suggests that the subjects were using the trace to predict the future target position. The reductions in tracking phase lags were associated with reductions in tracking errors. Results of Friedman analyses showed that as the 'look-ahead traces' lengthened, the radial tracking errors decreased (p<0.001).

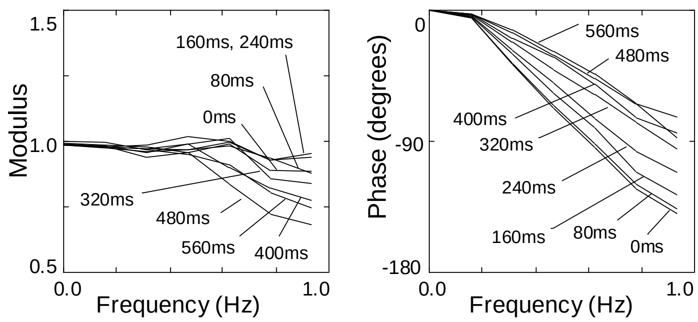

Figure 4. Yaw axis head tracking transfer functions with 'look-ahead traces' showing future target positions at different lead times (mean of 8 subjects' data).

The maximum phase lead information provided by the 'look-ahead traces' at 0.94 Hz are also shown in Figure 5. These phase leads are the phase differences between the present target position and the future target position presented at the forward end of the 'look-ahead trace'. At about 1 Hz, the mean reductions in tracking phase lags were less than the phase lead provided. This implies that the phase lead information provided by the trace was not fully utilized.

At about 1 Hz, the modulus (i.e. tracking gain) decreased as the trace duration' increased (p<0.005, Friedman). This indicates that the subjects may have changed their tracking strategies according to the duration of the 'look-ahead trace'. Yaw axis head tracking transfer functions were similar to those of the pitch axis. Subjective difficulty ratings decreased with increasing trace duration (p<0.001, Friedman).

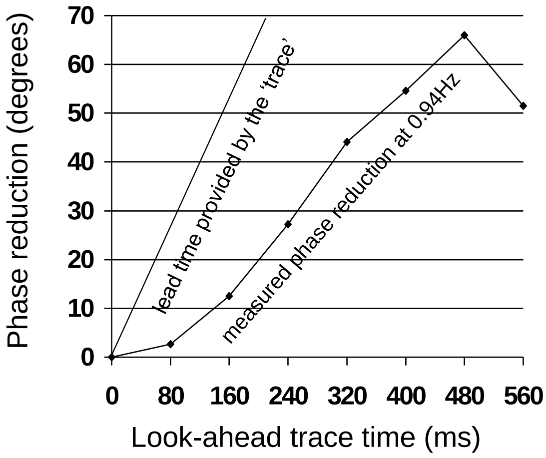

Figure 5. Reductions in head tracking phase lag at 1 Hz with 'look-ahead traces' showing future target positions at different lead times (phase leads provided by the traces are also shown (mean of 8 subjects' data).

4.0 CONCLUSIONS AND RECOMMENDATIONS

While tracking a circular target, the use of a 'look-ahead trace' can reduce the subjective difficulty rating, the head tracking phase lag, and head tracking errors.

Caution is required when using head tracking performance data obtained with circular targets to predict tracking performance with targets having shapes which indicate the direction or speed of movement of the targets.

5.0 ACKNOWLEDGMENT

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