

A COMPARISON OF HUMAN OPERATOR TRANSIENT  
RESPONSE TO VISUAL AND AUDITORY DISPLAYS

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Abstract: A comparison between various audio error displays and a visual display is made in terms of monitoring the change in the operator's response to a step change in the frequency bandwidth of the input signal. The operator describing function is modeled using a modified five-parameter cross-over model, and the applicability of this model during periods of transient response is verified

LIST OF SYMBOLS USED

$x(t)$  : band-limited Gaussian white noise with zero mean and variance  $\sigma x^2$ . As the cut-off frequency is varied the variance is maintained constant.

$e(t)$  : the error signal presented to the operator via the visual or audio display. The operator is required to minimize this error.

$z(t)$  : ( $= y(t)$ ) the operator's response to the error signal  $e(t)$  :  $e(t) = x(t) - z(t)$ .

$G(j\omega)$  : the forward-loop frequency response, incorporating the display, operator, and joystick dynamics.

$H(j\omega)$  : the overall closed-loop frequency response relating the input  $x(t)$  to the output  $y(t)$ . ( $= G / [1 + G]$ ).

$\Phi_{nn}$  : the power spectrum of that part of the output signal  $y(t)$  which is not linearly related to the input  $x(t)$ .

$\omega_0$  : frequency resolution ( $= 2\pi/T$ ).

$N$  : block size for Fourier analysis.

$T$  : block period.

$f_s$  : sampling frequency.

$M_A$  : magnitude of  $A$  ( $= |A|$ ).

$\theta_A$  : angle the vector  $\vec{O \rightarrow A}$  makes with the real axis in the complex plane. Thus  $A = M_A \exp(j \cdot \theta_A)$ .

$p(\bar{A}, \bar{B})$  : joint distribution of  $\bar{A}$  and  $\bar{B}$ .

$L$  : the number of independent estimates used to find  $\Phi_{xx}$ ,  $\Phi_{xy}$ , etc.

$S_x^2(K\omega_0)$  : half-power of  $x(t)$  in the bandwidth  $(K-\frac{1}{2})\omega_0 \leq \omega \leq (K+\frac{1}{2})\omega_0$ .

$S_r^2(K\omega_0)$  : half-power of  $r(t)$  in the bandwidth  $(K-\frac{1}{2})\omega_0 \leq \omega \leq (K+\frac{1}{2})\omega_0$ .

$S_n^2(K\omega_0)$  : half-power of  $n(t)$  in the bandwidth  $(K-\frac{1}{2})\omega_0 \leq \omega \leq (K+\frac{1}{2})\omega_0$ .

INTRODUCTION

Many models of the human operator response have been proposed. Briefly, these models fall into three categories: linear models,<sup>1</sup> sampled data models,<sup>2</sup> and nonlinear models.<sup>3</sup> For a wide range of applications it has been shown that the linear cross-over model on lines proposed by Krendel and McRuer (1953) gives a good approximation to measured human operator

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describing functions. Exceptions arise when the input signal to be tracked is of very low-frequency content ( $<0.2$  Hz) under which condition the operator exhibits a threshold-type nonlinearity, and when the input signal contains high-frequency components ( $>1.5$  Hz), when the operator degenerates into a "bang-bang" mode of control.

Comparison of various forms of multidimensional visual and tactile displays has been attempted<sup>5,6,7</sup> and, generally, results have indicated that the human operator responds equally well to visual and tactile presentation of information. Similar studies of one type of audio display<sup>8</sup> also indicate no appreciable loss of performance. Initial studies,<sup>22</sup> however, indicate considerable downgrading of the human operator's response to audio stimuli in one-dimensional tracking tasks.

In designing an audio display, either to complement or to replace a visual display, it is necessary to insure that the operator's performance is optimized, in terms of the display, for a wide range of operating conditions. In an earlier paper, a method of comparing and modeling an operator's response for various audio and visual displays was proposed. This paper investigates the operator's change in response for a step change in the dynamics of the input signal.

Section 1, together with Reference 22, outlines the experimental set-up and the types of audio and visual displays used. The operator describing function is modeled using a modified five-parameter cross-over model, and a plausible physical interpretation of the results in terms of the model parameters is presented.

The assumption that the model used is a good representation of the operator's response using audio displays, and that his response is essentially stationary for fixed-input dynamics, is investigated in Section 2. It is assumed that the model-describing function represents the true response of the operator and that deviations from this model during the test were because of short-term measurement inaccuracies due to noise in the system. This noise may be caused by nonlinearity in the response, uncontrolled

movements of the force joystick, and discretisation errors in the analogue-to-digital sampling (Fig. 1).

It is well known<sup>9,10,11,12</sup> that the human operator's mode of response depends on the dynamics of the plant to be controlled and on the frequency content of the signal to be tracked. The transient behaviour of the response to step changes in the plant dynamics has been investigated<sup>13</sup> for visual displays. In Section 3 the transient behaviour of an operator's response to step changes in the dynamics of the input signal is investigated for the audio and visual displays used. The response 'stationarity' and the applicability of the model during these periods of transient response are verified using the statistical results of Reference 23 (Chapter 3).

Section 4 outlines some problems involved in extending the analysis procedure to two-dimensional and multidimensional displays.

#### 1. COMPARISON OF HUMAN OPERATOR'S PERFORMANCE USING VISUAL AND AUDIO DISPLAYS

The results of this section are fully discussed in Reference 22. To avoid duplication, only the basic test procedure is outlined here, together with some further explanation of the phase response of the human operator at very low frequencies. Figure 1 is a schematic block diagram of the closed-loop configuration.

#### Summary of Method

The signals  $x(t)$ ,  $e(t)$ ,  $y(t)$ , and  $z(t)$  were sampled every 0.2 seconds. Short-term Fourier estimates were obtained using a block size of 128 samples. Five input cut-off frequencies were used, 0.3, 0.5, 0.7, 1.0, and 1.5 Hz. Each test, at a fixed cut-off frequency, lasted 10 minutes; thus, approximately 25 blocks of 128 samples were collected for each input cut-off. The average response of the operator was calculated from the mean values of  $\bar{\theta}_{xx}$ ,  $\bar{\theta}_{xe}$  and  $\bar{\theta}_{xy}$  obtained over the 25 blocks. The frequency response estimates were calculated (dependence on frequency is assumed) by:

