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Relating Eye Activity Measures to Human Controller Remnant Characteristics

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Abstract: This study attempts to partially explain the characteristics of the human perceptual remnant, following Levison's representation of the remnant as an equivalent observation noise. Eye activity parameters are recorded using an eye tracker in two compensatory tracking tasks in which the visual information is presented using either a first or second-order visual stimulus. Differences in the two conditions between remnant characteristics, eye activity measures and human operator model parameters are analyzed, using preliminary data from three subjects. Preliminary results show that the second-order visual stimulus introduces changes in both eye activity and remnant model parameters. Although high correlations are observed between remnant gain and blink frequency, between remnant break frequency and eye opening amplitude, and between remnant power and pupil diameter, a definitive conclusion about the perceptual remnant - eye activity characteristics relation cannot be drawn due to the small sample size of the obtained data. This preliminary study is a first step in identifying possible physiological parameters that affect the perceptual human remnant.

Keywords: manual control, human remnant, eye tracking, visual stimulus

1. INTRODUCTION

Linear transfer functions have been widely used to model human manual control behavior and can explain a large part of the mechanism behind it (McRuer and Jex, 1967). The part that can not be modeled by linear transfer functions, also denoted as the remnant, can be attributed to different sources, related to system noise and the exploratory nature of human behavior. A few examples include true observation noise (error in observing the task variables), motor noise, nonlinearities in the human controller (time-varying parameters, time delays), aperiodic sampling of the perceived variables Levison et al. (1969). As Flach (1990) mentions in his work on active psychophysics, the part of control signal linearly correlated to the input gives information on the task and performance of the human operator, whereas the remnant gives insight into the human operator himself. Levison et al. (1969) concluded that the remnant can be represented as an equivalent observation noise injected at the human operator's perceptual level that accounts for most nonlinear behavior. Even though the effects of different variables in the control loop on remnant models have been investigated, there are currently no studies that looked at the effect of changes in physiological eye parameters or in the perception of the displayed variables on the remnant characteristics.

The importance of a better understanding of the human remnant is two-fold. First, identifying and explaining certain sources of the remnant will give a better insight into whether the remnant is of physiological nature, an intrinsic perceptual process, or a combination of both. Second, more complex human operator models that account for human variability and other external environmental factors can be developed in order to better understand and predict human manual control behavior.

The goal of this paper is to investigate the possible relation between changes in physiological eye parameters, and changes in remnant model characteristics. The approach consists of a simple manual tracking task in which an eye tracker is used to capture changes in eye activity parameters. Visual information is presented either as a first or second-order visual stimulus. The remnant is obtained from the error signal measured from the control loop, and modeled as a first-order low-pass filter, according to Levison et al. (1969). The parameters of this filter are then correlated to changes in eye activity parameters. This study provides a preliminary insight on which eye activity measures are more likely to relate to changes in perceptual remnant.

2. BACKGROUND

2.1 Manual Control Task

Figure 1 depicts the control diagram for a typical single-axis manual tracking task. The goal of the human controller is to minimize the error e presented on the display by providing control inputs u which are transformed into the output y through the controlled dynamics H_c. The input forcing function is denoted as f_i. The human con-

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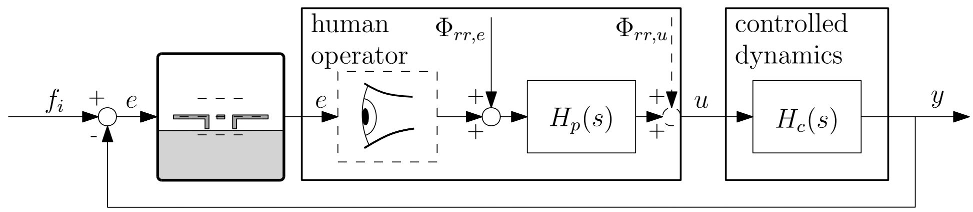

Fig. 1. Control diagram of a manual tracking task.

troller is composed of two parts: a linear transfer function which includes equalization dynamics and neuromuscular limitations, and a remnant signal, $\Phi_{rr,e}$ which accounts for the control behavior not linearly correlated with the frequencies of the forcing function. Note that, since $H_p(s)$ is a linear transfer function, the remnant signal can also be injected in other locations in the control loop, for example at the human operator's control output u, as represented by the signal $\Phi_{rr,u}$ in Figure 1. However, since the goal of this paper is to investigate how changes in perception affect the remnant obtained at the input of the human operator, we chose to add this signal to the perceived error e. This provides a mathematical tool to most directly compare changes in the remnant characteristics with changes in eye activity parameters.

2.2 Remnant modeling

In this study, an investigation on how changes at the perceptual level affect remnant characteristics is carried out. Thus, the need of a model to capture remnant characteristics is evident.

In their early work, McRuer et al. (1965) concluded that the remnant power spectral density is a smooth function of frequency and that its most consistent representation is as an equivalent observation noise injected at the controller's input. Moreover, their work showed that the order of the controlled dynamics has a big impact on remnant characteristics. In addition, Pew et al. (1967) reported that the remnant spectrum is invariant to the bandwidth of the forcing functions and display gain. Later research by Elkind et al. (1971) confirmed these findings, showing that an equivalent observation noise at the human controller's input, normalized by the variance of the error, is invariant to the input characteristics, ultimately meaning that the absolute remnant power scales with the magnitude of the error.

Levison et al. (1969) concluded that, if observation noise signals following Weber's law act on each state of the perceived variables (e, $\dot{e}$), then the equivalent *normalized* remnant spectrum at the perceptual level can be represented by a first-order low-pass filter model. The power spectrum of such a model is given by:

$$|\Phi'_{rr,e}|^2 = \frac{|\Phi_{rr,e}|^2}{\sigma_e^2} = \frac{K_r}{1 + T_r^2\omega^2}, \quad (1)$$

where K_r represents the gain of the remnant, T_r is a constant that dictates the ratio in the perception gains on the error rate ($\dot{e}$) and error displacement (e), and ω denotes the frequency vector. Note that the remnant break frequency is given by $\omega_r = 1/T_r$.

This model has been validated by Jex and Magdaleno (1969), in a study that compiled remnant data obtained from numerous experiments. As mentioned before, remnant characteristics are affected by the order of the controlled dynamics. It was experimentally found that, for controlled dynamics of the form $H_c(s) = 1/s(sT_c + 1)$, where the time constant T_c is neither two small nor too large, the remnant model has two identifiable parameters, both K_r and ω_r. However, T_c approaching zero or infinity will also result in the remnant break frequency to become infinity or zero, respectively, meaning that the only identifiable parameter in Equation 1 is the gain K_r. A typical example of a *normalized* remnant spectrum at the human controller's input is shown in Figure 2.

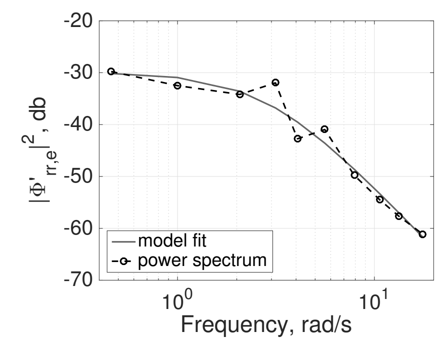

Fig. 2. Power spectrum of the perceptual remnant (K_r = -29.93 db, ω_r = 2.86 rad/s)

3. METHOD

3.1 Changing the Perceptual Remnant

In subsection 2.2, a model for the remnant at the perceptual level of the human operator is introduced. The perceptual channel at the input for the human operator block diagram in Figure 1 is composed of the human's visual system that perceives and processes the task variables (error displacement, error rate) displayed on the screen. Since the interest is to analyze how changes at the perception level affect the behavior of the remnant parameters, some mechanism that induces changes at this level is needed.

In psychophysics, two types of motion stimuli are defined. The visual system extracts motion information from a first-order stimulus using difference in the luminance of objects. However, in case of isoluminance, the visual system relies on differences in contrast, texture or spatial frequency in order to obtain motion information. Multiple studies suggest that motion perception in the two cases relies on different mechanisms inside the visual system (Chubb and Sperling (1989); Ledgeway and Smith (1994)).