Effect of Extended Visual Feedback on Human Information Processing in Virtual Stick Balancing

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ABSTRACT

Maintaining vertical position of an inverted pendulum is a simple balancing task, which is widely used to study human control behavior. Yet, much about this behavior remains poorly understood even in the context of simple virtual tasks. The purpose of this study was to investigate whether the control behavior of human operators depends on the type of visual feedback from the controlled system. We analyze the experimental data on human stick balancing on a computer screen. The previous studies reported detailed analysis of the task performance of human operators observing only the angular deviation of the stick from the vertical. In this study we augmented the information supplied to the operator by linear displacement of the upper tip of the stick from the reference point. This additional information was suggested to improve the performance of the operators. Surprisingly, the subjects not only exhibited better performance, but also supposedly employed structurally different control mechanisms in the linear displacement condition. The found results may have potential implications both for fundamental research aimed at investigating the basic properties of human control, and applied research on human factors.

Categories and Subject Descriptors

H.1.2 [**User/Machine Systems**]: Human information processing

Keywords

Stick balancing, Motor control, Intermittent control, Human operator, Human-machine interaction

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1. INTRODUCTION

Understanding how humans control unstable systems is a key issue in numerous applications, ranging from quiet standing to aircraft landing [7]. The task of stick balancing (Fig. 1) has been extensively used as an experimental paradigm for studying behavior of human operators controlling unstable systems [6, 5]. In different variations of this task studied in literature, human operators are provided with different information about the balanced stick. When balancing a stick on the fingertip, humans employ both visual and proprioceptive signals to control the stick (see e.g. review in Ref. [5]). In the paradigm of virtual stick balancing on a moving platform, typically only visual feedback on the system state is available for the operator [1, 6]. Although both the real and virtual balancing approaches often converge on the similar findings about the overall control properties (see e.g. [1]), little attention has been paid to the differences in the operators' behavior under different conditions of balancing task. Such differences, if any, may have profound impact on the methodology of experimental studies on human balancing behavior. Besides theoretical value, elucidating the effect of visual feedback on human operator performance can have potential implications for applied studies on human factors. For instance, it is long known that proper setup of visual displays can enhance the performance of human operators [7], which is particularly important in life-critical tasks such as airplane landing.

The purpose of this study was to investigate whether the control behavior of human operators depends on the type of visual feedback provided by the controlled system, using as an example the task of virtual balancing of overdamped stick. This task has been previously confirmed to provide a useful insight into properties of human control in diverse processes, e.g. quiet standing and car driving [5, 8].

Particularly, we analyze the data on human balancing of virtual stick obtained under two different conditions. In the first condition (which had been analyzed previously in details [8]), the subjects controlled the stick guided only by its

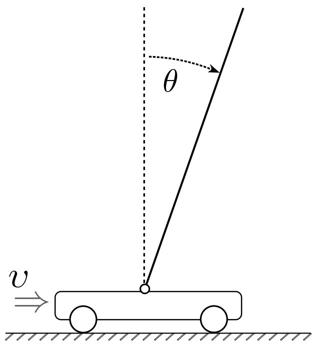

Figure 1: Inverted pendulum (stick) on a moving cart.

angular deviation from the vertical. The newly conducted experiments focused on the second condition, where the subjects not only observed the stick angle, but were also able to monitor the *linear displacement* of the upper tip of the stick with respect to a dynamic reference point. The two chosen conditions reflect the two classes of experimental paradigms employed in modern literature on human balance control. One of these classes comprises experimental setups where the subject only observes the angle of the balanced object (e.g. [2, 5]), and the other one focuses on the subjects matching the actual position of the upper tip of the virtual stick and the reference position of the upper tip when the stick is in vertical position (e.g. [1, 4]).

The experiments revealed that availability of the linear displacement in addition to the angular deviation information substantially improved the balancing performance of the subjects. The most surprising result, however, was that the additional visual feedback not only reduced the amplitude of the stick fluctuations under human control, but also resulted in the structurally different statistical distributions characterizing the control process. This suggests that human operators employ different control mechanisms depending on the particular type of information about the controlled system is available (linear or angular). Besides theoretical value, our findings may have potential implications for design of visual displays for human operators.

2. EXPERIMENTAL SETUP

This study analyzes human behavior during the task of balancing virtual overdamped[1] stick on the computer screen (Fig. 1). The goal of the task is to keep the stick upwards, whereas the cart position is controlled directly by a computer mouse, so the cart can be moved arbitrarily within the limits of the computer screen.

The physics of the overdamped stick is governed by the differential equation

$$\tau\dot{\theta} = \sin\theta - \frac{\tau}{l}\upsilon\cos\theta, \tag{1}$$

where θ is the stick angle, the cart velocity υ is the control variable, $\tau > 0$ is the constant time scale of the stick motion, and $l > 0$ is the length of the stick.

[1]The overdamping condition is essential, because it simplifies the analysis of the human behavior dynamics (see Ref. [8] for discussion)

In what follows we investigate two datasets. The first one has been obtained previously [8], and includes the data for ten subjects (six male, four female, aged 20 to 61), who performed the balancing task while observing only the cart and the stick on the computer screen. Each subject balanced the stick during three five-minute sessions, separated by two three-minute breaks. The kinetic parameters of the stick were set to $\tau = 0.3$, $l = 0.4$. The detailed description of the obtained data can be found in Ref. [8].

The second dataset has been obtained in the newly conducted experiment, which significantly differed from the previous one only in the type of visual information provided to subjects. In this new experiment, the subjects were shown not only the coupled cart-stick system, but also the mouse cursor on the computer screen. The subjects were specifically instructed to balance the stick by keeping the mouse cursor near the upper tip of the stick. We hypothesized that this would greatly simplify the task for the subjects, because even the smallest deviations of the stick from the vertical position can be easily detected and corrected in this case.[2] The eight volunteers (six male, two female) participated in the new experiment were aged from 23 to 63 years old, and four of them took part in the experiment reported in Ref. [8].

3. RESULTS AND DISCUSSION

The question we aimed to answer in this study is: Besides the expected quantitative difference, are there any fundamental, *qualitative* difference between the two conditions? For this purpose, we analyze the statistical distributions of the stick angle and cart velocity data (Figs. 2,3).

The distributions of the stick angle under two conditions were found to be markedly different (Fig. 2, left frame). Based on this fact, and given that the physics of the controlled system is the same in the two conditions, and only the type of the visual feedback differs, we conclude that human operators employ different control mechanisms when using the angular and linear visual information. At the same time, the distributions of the cart velocity in the "With cursor" and "No cursor" conditions exhibit the same form, which in turn indicates that the corrective movements executed by the operators have the same generating mechanisms.

Taking into account these considerations, and appealing to the hypothesis of discontinuous, or intermittent control [3, 5], we hypothesize that the key difference between the operators' behavior in the two analyzed conditions lies in the domain of the *control activation* mechanism. To investigate this assumption further, we analyze the *action point* (AP) distributions (Fig. 3). In the context of the present work, an action point is a value of stick angle triggering the corrective action of the operator. Each AP corresponds to an instant when the operator begins to move the cart in response to the deviation of the stick from the vertical position. Thus, the AP distributions highlight the stick angle values which are likely to trigger reaction of human operator in each condition.

We found a pronounced difference in the AP distributions under two conditions, which indicates that different control

[2]By design of the simulator software, the horizontal position of the moving cart on the screen was the same as the mouse cursor position. Hence, if the stick deviated to the right of the cursor, simply adjusting the cursor position to the upper end of the stick would eliminate the deviation.

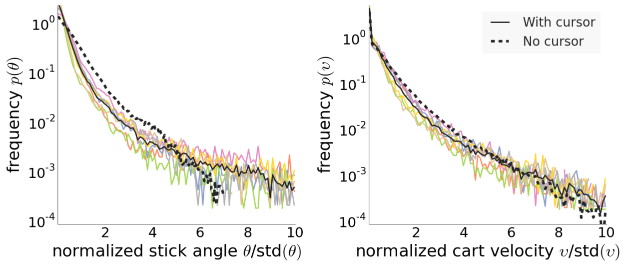

Figure 2: Distributions of stick angle and cart velocity exhibited by human operators in virtual stick balancing under the two tested conditions. Colored solid lines represent the individual distributions for each subject for the "With cursor" condition, whereas solid and dashed black lines show the average distributions for all the subjects in the "With cursor" and "No cursor" conditions, respectively.

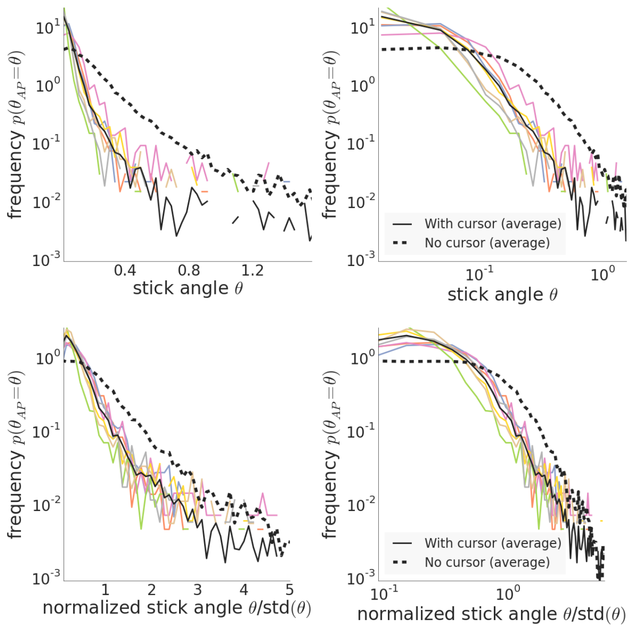

Figure 3: Distributions of action points (AP) exhibited by human operators in virtual stick balancing. The colored lines represent the individual distributions in the "With cursor" condition for each subject, whereas solid and dashed black lines show the average distributions for all the subjects in the "With cursor" and "No cursor" conditions. The top two frames illustrate the *scales* of the distributions in the two conditions. The bottom two frames (the stick angle values are normalized with respect to std(θ)) demonstrate the structural difference between the two distributions.

activation mechanisms are employed by the operators provided with different types of visual feedback. If the the information about linear deviation is available ("With cursor" condition), the AP distribution peaks at a small angle, and decreases much faster than in the case when only the angular deviation is supplied to the operator. Moreover, the log-log plot of the AP distributions (Fig. 3, bottom right plot) demonstrates that the tail part of the "With cursor" distribution may follow a power law (a straight line in the log-log scales), as opposed to the "No cursor" one, which can be approximated by the Laplace distribution [8].

Although our results highlight the difference in the control activation mechanisms under two tested conditions, this work leaves unanswered the question as to what these mechanisms are. At this point, we can only claim that humans' visual perception of information on angular deviations differs from that of linear displacements, and that it results in different pattern of control activation (at least in the task of virtual stick balancing). However, to be able to speculate about the particular mechanisms, one should confront the data presented here to the various models of control activation, including threshold-based [3, 5] and noise-driven [8] models.

4. CONCLUSION

The present study investigates actions of human operators in a simple virtual balancing task, namely, maintaining vertical position of an overdamped inverted pendulum. We focus on the effect of visual feedback type on the performance of the operators, providing the subjects with two types of visual feedback — angular deviation and linear displacement. We analyze the previously collected and newly obtained experimental data. The analysis reveals that the statistical properties of the stick under human control under two considered conditions differ not only in scale, but also qualitatively, as highlighted by the distribution of the stick angle and action points (Figs. 2,3). This suggests that one must be aware of the potential differences in human control mechanisms even in the case when the difference between the experimental conditions is seemingly minor.

We conclude that while the control execution mechanisms supposedly do not change depending on the type of visual feedback, the *control activation* exhibited by the subjects are substantially different. One may even assume that humans' processing of angles is governed by different cognitive mechanisms than that of linear displacements. However, the latter assumption is to be reinforced by appropriate modeling in the future studies. In any case, the very fact that control activation in human operators' essentially depends on the type of visual feedback may have potential implications both for fundamental research aimed at investigating the basic properties of human control, and applied research on human factors.

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