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Virtual Stick Balancing：Distribution of Time Delay of Human Response

倒立棒制御の仮想実験による人間の応答の遅れ時間の分布推定

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1. Introduction

Most machines are operated by humans. When humans operate machines or vehicles, they often make mistakes. Humans are able to make flexible judgments which can adapt to environmental changes but they make mistake at times. On the other hands, they can avoid serious accidents to make up for the faults of machines. These mistakes are called human errors. For the last 10 years, about 23% general aviation aircraft accidents were caused by controlled flight into terrain [1]. For the most part these errors are committed by people who are trying to do their job professionally and carefully. Because of that, it must be recognized that human errors are a component of normal human behavior. So, such human operations and machines which cannot be well-controlled with the exception of instruction program sometimes cause serious accidents. It is desirable that control designs of machines are optimized to reduce serious accidents caused by human error. We do this by understanding the essence of machine operation by humans. In other words, human cognition and response characteristics should be understood more quantitatively.

There are two levels on human control behavior. First one is the direct control behavior which is the lower order level like reflective movement. Second one is decision-making, which is the higher order level and needs complex knowledge and judgment. In this research, we focus on the direct control behavior.

The direct control behavior consists of three basic properties: time delay, prediction, and intermittency [6]. In our former research, these properties were investigated by using the simple stick model control simulation [2,3]. However, quantitative evidence was not enough to determine these three kinds of basic properties.

In this research, we focus on estimating distribution of time delay of human response among the three properties.

In previous research[4], the time delay is estimated 220±30ms using a human and computer hybrid simulation experiment shown as in Fig. 1. Here, the following auto regressive and moving average (ARMA) process are used to estimate the delay time of human response:

$$y(\mathrm{t}) + a_1 y(t-1) + \cdots + a_n y(t-n) =$$
$$b_1 d(t-n_k) + \cdots + b_n d(t-n_k-n+1) + e(t)$$

However, it is possible to evaluate only average time delay of human response in this method but the time delay of human response is essentially a random property having some distribution. So, in this research, we develop human-computer hybrid simulation model to directly estimate distribution of time delay and then conduct experiments using this simulator.

The remainder of this paper is structured as follows: Section 2 introduces the stick balancing simulator for estimating time delay; Section 3 discusses distribution of time delay measured by the experiment. Section 4 presents conclusions.

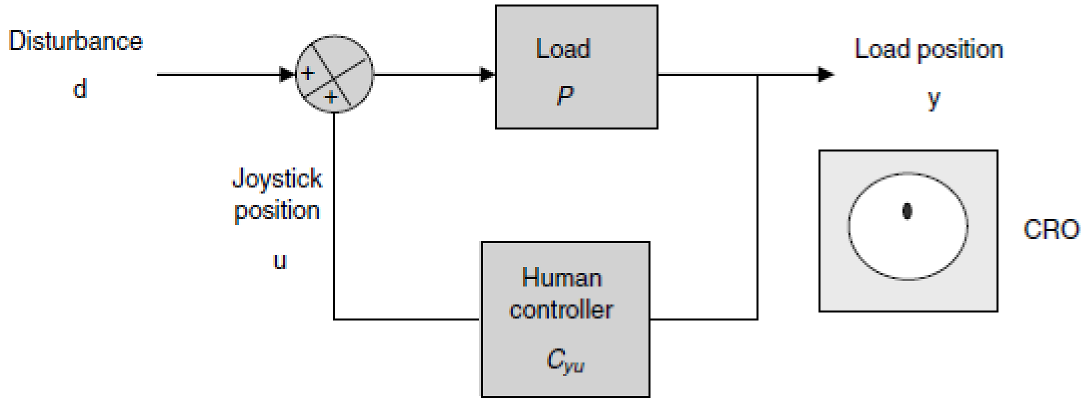

Figure 1. Visually guided manual control of stable and unstable loads [4]

2. Method

2.1 Virtual stick balancing model

We consider well-known control model of stick balancing near the vertical position. We focus on simulation of stick motion in viscous environment using computer in this research. The dynamical model of stick is described by the following dimensionless mathematical model[2]:

$$\tau\frac{d\theta}{dt} = -\cos\theta + A\cdot v(t)\cdot\sin\theta$$

Here, θ is the angle of stick, $v(t)$ is velocity of cart motion which is the control parameter affected by human operator. τ is the time scale characterizing the stick motion. A is the amplifying coefficient of the control effort.

This model can be discretized with the time step Δt as follows:

$$\theta_t = \theta_{t-\Delta t} + \frac{-cos\theta_{t-\Delta t} + A\cdot v_{t-2\Delta t}\cdot sin\theta_{t-\Delta t}}{\tau\cdot\Delta t}$$

Here, we assume $v_t \approx v_{t-2\Delta t}$ in the right hand side second term.

$v_{t-2\Delta t}$ is calculated by the following interpolation formula [5]:

$$v(t-2\Delta t) = \frac{x_{t-2\Delta t} - x_{t-3\Delta t} + 2(x_t - x_{t-4\Delta t})}{10\Delta t}$$

Here, x_t is a mouse position of horizontal direction at time t.

Time step Δt is set as 20 msec in the present experiment. This period is sufficiently short by considering typical human response time of 200 - 300msec, and stick motion time scale τ which is set as 300-700 msec.

2.2 New stick balancing simulator

We developed the new stick model (Fig.2) to directly estimate distribution of time delay. The new stick model is different from the original stick balancing simulator (Fig.3) in visible area of stick.

We develop new simulator which hides stick in $\pm$ 5 degree from vertical state to directory estimate the time delay. Since the stick suddenly appears when it stray off stick hidden area, human operators try to control the stick keeping it from falling down with some time delay. Then, we can measure this time delay by counting the duration between stick appearance time and mouse first movement time. We set that initial state as a random area from -5 to 5 degree. It enables us to make difficult to predict the stick appearance direction and time, and, this contributes to increase the accuracy of delay time measurement.

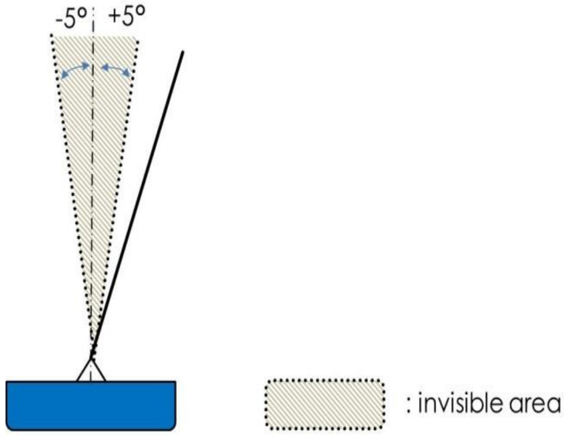

Figure 2. 5-degree of view hidden stick balance simulation

(Newly developed simulator)

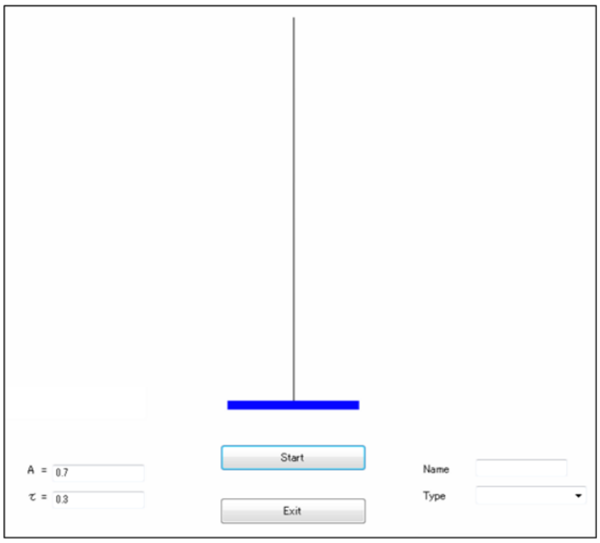

Figure 3. The original stick balance simulation system

2.3 Subject for experiments

It is necessary that these experiments are conducted on different types of participants to evaluate effect by personal skill of computer manipulation, age, etc. So, we chose a total of 6 subjects as follows:

- two young males who are familiar with present experiment,
- one young student who is familiar with computers but not familiar with the experiment,
- two senior males who are familiar with computers but not familiar with the experiment,
- one senior female who is not familiar with computers.

2.4 Experimental rules

We set 5-minute exercise session to allow familiar with the simulator manipulation before the main experiment of delay time measurement. Participants conducted stick balancing controls 100 times in one experiment. It is not possible to estimate distribution of time delay in case of less than 100 times trial because there are variations in distribution. We offer break of up to 3 sec between trials because it is necessary for participants to prepare for the next trial. In first trial, participants have to push start button to start experiment but they do not have to push start button to reduce noises caused by unnecessarily moving mouse. And, mouse position is automatically moved to the original position after every trial to exactly measure the time delay under the same experimental conditions.

2.5 Time delay measurement method

We collected experimental data which consists of stick angle, angle velocity, mouse position and velocity every 20 msec. After that, we analyze this data to estimate distribution of time delay. So, first, we extracted the mouse velocity data of 1 second for every trial after first stick appeared. Namely, the initial time of each trial data was set to zero when the stick angle becomes less than 85 degrees or more than 95 degrees. After that, we measured the time when velocity changed from 0 to a certain value, that is, when participants started to move the cart.

2.6 Removal of noises

There are some noises during the experiment. For example, participants moved mouse a little by error, noises were caused by failure of mouse before stick was shown (Fig.4). So, we had to ignore change of velocity before stick was shown, or, too this caused early mouse manipulation.

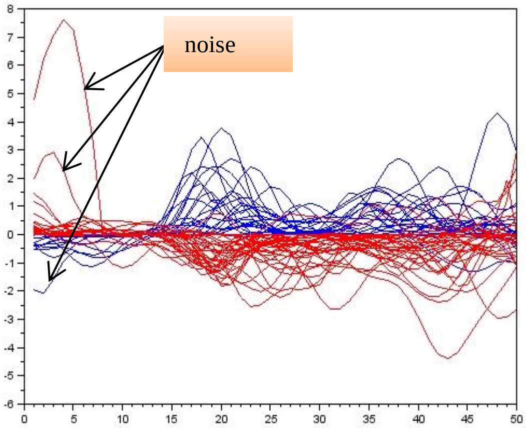

Figure 4. Example velocity response and noises

3. Result

We confirm the virtual stick balancing simulator by this experiment. The results of distribution histograms of time delay for typical four participants are shown in Figs. 5 to 7. Here, x-axis is measured time delay and y-axis is its frequency. Figure 5 compares the young male who is familiar with present experiment (blue line) and the senior male who is familiar with computer but not familiar with this experiment (red line). Figure 6 compares young male who are familiar with present experiment and senior female who is not familiar with computer and the experiment. Figure 7 compares young male who are familiar with present experiment and male who is familiar with computer but not familiar with the experiment.

It is seen that we can obtain similar distributions of time delay in this experiment regardless of skills, ages, etc. For the most part time delays are distributed about 0.2 to 0.5 second in these histograms, which corresponds to other estimates of the human reaction delay reported previously for tracking or monitoring systems with unpredictable dynamics [6]. The most essential result found in the present work is the fact that all these histograms are rather wide. In other words, the delay time in human response is demonstrated to be a widely distributed variable. Indeed, according to the obtained results, the width of these distributions is considerably larger than the minimal delay time observed for almost all the subjects. It poses a question as to whether the concept of fixed delay time is appropriate for describing human control. If not so, the mathematical formalism based on the delayed differential equations become inapplicable.

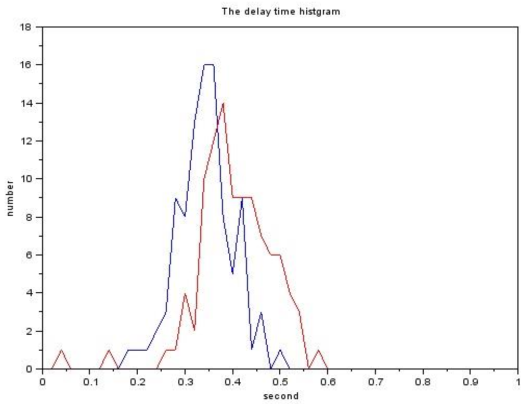

Figure 5 Young male who is familiar with the experiment (blue) VS Senior male who is familiar with computer is not familiar with the experiment(red)

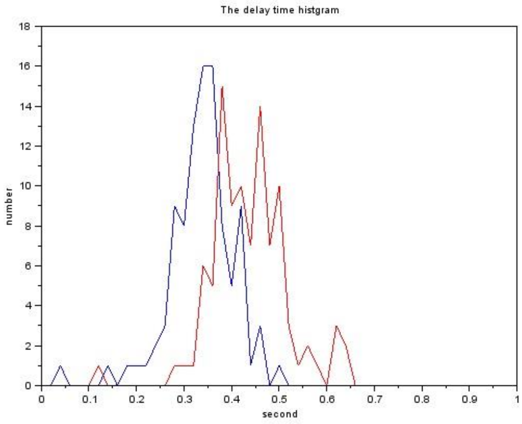

Figure 6 Young male who is familiar with the experiment(blue) VS Young male who is familiar with computer but not familiar with the experiment(red)

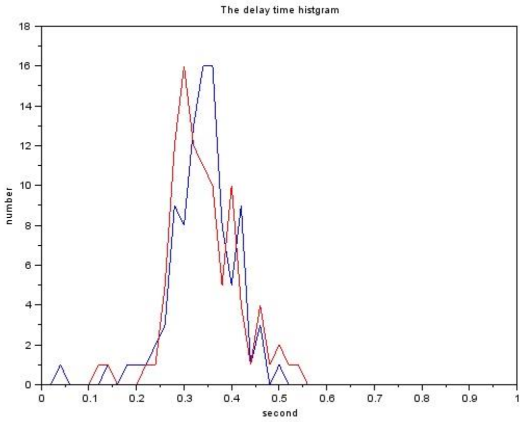

Figure 7 Young male who is familiar with the experiment(blue) VS Senior female who is not familiar with computer and the experiment(red)

4. Conclusion

We focus on estimation of time delay which is one of the basic characteristic of human control system by conducting virtual stick balancing experiment. We develop new stick balancing simulator model (5 degree view hidden model). This simulator should enable us to directly measure distribution of time delay.

Various type participants are prepared for the experiment. We analyze effect of ages, skills, and so forth on distribution of time delay. This experiment includes 100 times trial, so it is enough to estimate the distribution of time delay. The newly developed simulator is reduced unnecessary participants operation so it enables to interrupt input of otiose noise

There are some problems in this experiment. First, it is incomplete method to remove noises. So, we consider method of removal noises. There are few participants in this experiment. So, distribution of time delay becomes more accurate model to increase the number of participants.

The found fact that the human delay time is a widely distributed variable enables us to pose a question about the appropriate mathematical formalism required to model human control. In any case the notion of the delayed differential equations seems to be inapplicable. Now we can propose for consideration two possible directions. First one is a probabilistic description of the human reaction to events where the delay time is a random variable based on the master equation. The second one appeals to the idea about human fuzzy reaction. Namely, the position of the object under control is regarded as a certain function of the spatial coordinates rather than a point. From out point of view the latter is more prospective and seems to require a mathematical formalism similar to that developed in quantum mechanics.

5. Acknowledgement

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[4] Visual control of stable and unstable loads: what is the feedback delay and extent of linear time-invariant control? Ian D. Loram1, Martin Lakie2 and Peter J. Gawthrop3 1Institute for Biomedical Research into Human Movement and Health, Manchester Metropolitan University, John Dalton Building, Oxford Road, Manchester M1 5GD, UK 2Applied Physiology Research Group, School of Sport and Exercise Sciences, University of Birmingham, Birmingham B15 2TT, UK 3Department of Mechanical Engineering, Centre for Systems and Control, University of Glasgow, Glasgow G12 8QQ, UK

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