Delay, Noise and Resonance: Human balancing and temporal non-locality

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Abstract: We would like to present here a rather peculiar observation during human stick balancing at his fingertip. It is observed that the balancing time improves when the subject moves objects with the other hand. This is particularly so for many subjects with medium skill of stick balancing. Based on this example, we would like to consider how this seemingly simple task is composed of intricate mixtures of feedback delay, fluctuations, and predictions. We will present some simple models of dynamics in which these factors lead to complex behaviors. It is inferred, from these examples, that the concept of "non-locality" could possibly play an important role in characterizing biological and physiological systems.

Keywords: Delay, Noise, Resonance, Balance Control, Non-locality

I. INTRODUCTION

Stick balancing in upright position is a topic which has been investigated much in mechanics and control theories. Human stick balancing on his fingertip appears as a very simple task. It is, however, rather intricate combination of physiological feedback delays, predictions under the influence of fluctuations. In particular, we have found that if one moves objects with the other hand, balancing of sticks becomes easier. This rather unexpected effect indicates that human stick balancing could be far different from the ones studied in control engineering. From this effect, we would like to discuss if the concept of "non-locality" could play an important role in describing biological and physiological systems.

II. STICK BALANCING

Let us describe the experiment of human stick balancing. A subject is asked to sit on a chair and balance on his fingertip a wooden stick of about half a meter length. In the original experiment done by Milton and Cabrera[1-3], they measured the time duration of balancing a stick before its fall as well as tracking the motions of the top of the stick and the fingertip. They found that the motion of the stick shows small amplitude fluctuations with intermittent large movements. Our experiment is to add in an extra fluctuations or rhythmic movements on this basic experimental paradigm[4-6]. The motivation to introduce such external fluctuations comes from inference to the effect of stochastic resonance (Fig 1), which we shall describe briefly in the next section.

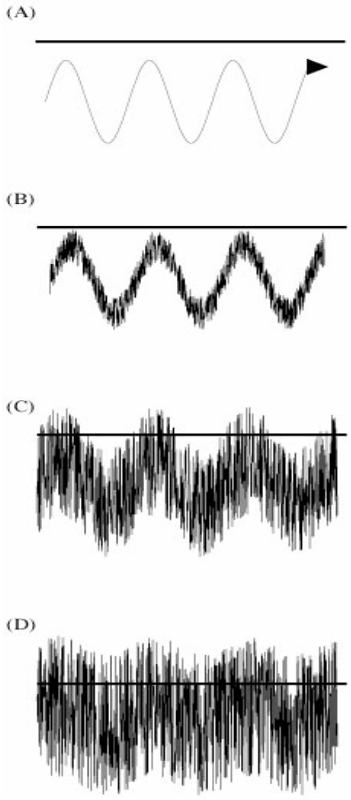

Fig.1. Schematic view of Stochastic Resonance. (A) a sub-threshold incoming oscillatory signals. (B) Small amplitude noise added, but still undetectable. (C) Appropriate amplitude noise added, the signal is now detectable and reflecting some nature of underling oscillatory signals. (D) Too large amplitude noise added, detectable but incoming signals characteristics are lost.

III. STOCHASTIC RESONANCE

Normally, noise or fluctuations are considered as an obstacle to information processing systems. However, in nature, there appear to exist examples that noise has a beneficial effect through a resonance like effect. These systems are investigated under the name of "Stochastic resonance"[7-9]. One representative example is the detection of sub-threshold oscillating signals with added noise of appropriate strength (Fig.1). Other types of mechanisms have been also investigated, leading to variety of applications[10-15]. This concept of beneficial effect of fluctuations motivated us to consider it in the context of stick balancing.

IV. STICK BALANCING WITH FLUCTUATIONS

Based on the inference from stick balancing, we have added fluctuations in various ways during human stick balancing. The original idea was to shake a bottle of water with the other hand (Fig. 2). Then, we have tried subjects to stand on a vibrating platform. On both schemes, we have found the following.

(1) It takes a bit of practice to balance a stick with added fluctuations.

(2) However, for people with medium level of skill in the stick balancing, added fluctuation leads to longer balancing time.

(3) For those people with poor or very good skills, added fluctuations did not help or acted as a disturbances in balancing.

Fig.2. A subject moving an object while balancing a stick

Typically, the improvement in balancing time with added fluctuations ranged from 20 to 50 percent.

Our current hypothesis on this effect is as follows. We tend to view ourselves like a machine which could control the stick very fast with our visual feedback and predictions of its motion. However, in reality this control is highly unstable, and due to our physiological delay, our control ability is not fast enough or accurate enough to keep stick balancing, if we rely too much on our feedback loop. Thus, it is constructive to cut this reliance on the feedback control loop occasionally. The added fluctuations help in this cutting of the control loop at appropriate levels.

We should note that there is a mathematical study on so-called "wait and act" controls[16-18] which are proved to be effective in the presence of delay in the feedback control loop. It requires a further investigation to see if the added fluctuations in the human stick balancing task relates to the framework of such controls.

V. NON-LOCALITY IN BIOLOGICAL SYSTEMS

Another issue which emerged from our experiment is the question if the concept of "non-locality" could be important in characterizing biological and physiological systems. Moving an object with the one hand, at first sight, would have nothing to do with the balancing of the stick on the other hand. At least, it goes outside of the traditional thinking of engineering. Also, delay could be considered as non-locality[19,20] on the time axis in the sense the system's behavior is not only decided by its current state, but also depends on a separated temporal point in the past. So, even in this seemingly simple task of stick balancing may involve various factors in both spatial and temporal non-localities. In physics, the concept has been puzzling separating classical and quantum physics and still much effort is underway to understand its nature. It could be also true that the concept of "non-locality", though probably different from that of physics, may serve to characterize biological or physiological systems.

VI. CONCLUSION

In this paper, we have introduced our observation that added fluctuations help in human stick balancing controls. It may be considered as another example of

Stochastic Resonances. Also, we inferred that concept of non-locality in both space and time may be important in biological systems, which requires more explorations.

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