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Understanding of Positioning Skill based on Feedforward / Feedback Switched Dynamical Model

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Abstract— **To realize the harmonious cooperation with the operator, the man-machine cooperative system must be designed so as to accommodate with the characteristics of the operator's skill. One of the important considerations in the skill analysis is to investigate the switching mechanism underlying the skill dynamics. On the other hand, the combination of the feedforward and feedback schemes has been proved to work successfully in the modeling of human skill. In this paper, a new stochastic switched skill model for the sliding task, wherein a minimum jerk motion and feedback schemes are embedded in the different discrete states, is proposed. Then, the parameter estimation algorithm for the proposed switched skill model is derived. Finally, some advantages and applications of the proposed model are discussed.**

I. Introduction

The man-machine cooperative system is attracting great attention in many fields, such as manufacturing, medicine, welfare and so on. To realize the harmonious cooperation with the operator, the assisting system must be designed so as to accommodate with the characteristics of the operator's skill.

Authors have developed the human skill model based on a hybrid dynamical system modeling under the consideration that the operator appropriately switches some simple motion control laws instead of adopting the complex nonlinear motion control law [1][2]. In [1], the positioning task was particulaly focused on and considered as the reaching task with precise adjustment. This task was identified as the variable gain feedback control based on the hybrid system framework[3].

From the viewpoint of biology or computational nueroscience, there are number of studies indicating that the feedforward control is dominant in the voluntary movements[4][5]. A reaching movement is considered to be achieved by a combination of trajectory planning, such as the minimum jerk trajectory[6][7][8], and the inverse dynamics to realize the trajectory[9]. On the other hand, it is also reported that the feedback infomation, such as the visual infomation, is necessary to accomplish the precise control[10]. Therefore, the combination of the feedforward and feedback schemes seems natural, however, it is unlikely that the human always activate both the feedforward and feedback schemes simultaneously. It seems more natural that the feedforward and feedback schemes are switched smoothly according to the progress of the task. From this viewpoint, this paper proposes a new stochastic switched skill model for the sliding task wherein the feedforward and feedback schemes are embedded in the different discrete states (FF/FB switched skill model).

In particular, in the discrete state of the feedforward scheme, a minimum jerk motion[8] is embedded, while in the discrete state of the feedback scheme, a standard linear feedback control law is embedded. Then, the parameter estimation algorithm for the proposed FF/FB switched model is derived. One of the promising applications of the proposed model is the estimation of the switching condition from the feedforward to feedback scheme based only on the observed data. The estimated switching condition can be exploited for the design of the switched assisting controller wherein the assisting mode is switched according to the change of the operators control mode. Furthermore, the proposed model can be exploited for the skill recognition which is available for the analysis of experience, skillfulness, and so on.

II. Sliding task and data acquisition

Throughout this paper, the sliding task shown in Figs.1 and 2 is considered. The developed system consists of one d.o.f. linear slider controlled by the impedance control. The impedance parameters were set as follows; the mass M, the damping D and the stiffness K were set to be 5[kg], 10[Ns/m] and 0[N/m], respectively. These parameters were found by try and error. The force sensor is attached on the slider head to detect the examinee's force which is used for the impedance control. The position x_t, the velocity $\dot{x}_t$ and the acceleration $\ddot{x}_t$ of the slider head are observed every 200[μsec] and used for the skill modeling. The examinee was requested to manipulate the grip toward the target position (origin), and to stop it in the range of -3[mm] to 3[mm]. This positioning accuracy requires the feedback control scheme in the operator's action. The moving distance was set to be 400[mm]. In this experiment, twenty trials have been made by three examinees. As an example, one of the profiles of the examinee A is shown in Fig. 3. The horizontal axis represents the time and the vertical axes represent the position, velocity and acceleration, respectively.

III. FF/FB switched skill model

A. Structure of proposed model

For the sliding task shown in Section II, it is quite natural to consider that this task is achieved by both the feedforward scheme and the feedback control scheme. In the early part of the task, the feedforward scheme must be dominant

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