Identification of a Human Standing Controller From Motion Loci

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***Abstract*— A human standing controller is identified as a dynamical system. The whole-body motion is approximated by COM-COP (the center of mass and the center of pressure) model, where COP is manipulated so as to regulate COM. It is an identification of piecewise-affine system, which is difficult since the system segments and parameters should be found simultaneously. *K*-means method and EM algorithm were applied to this problem. The result shows that COM-COP regulator model well approximates the standing controller.**

I. Introduction

This work aims to identify the human motor controller *without observing the brain activity*. It is still difficult to understand how brain coordinates highly-articulated whole-body. The authors thought that some works[1] in humanoid robotics would suggest a model of a human controller since they stand on the mechanics of an anthropomorphic system, which could be the real human.

The idea is to collect a number of motion loci in the phase space and conduct system identification. The authors did the motion measurement of a human subject in stance and saw that measured behavior was similar to the system in theory[2,3]. However, the system identification has not been completed since it is a difficult chicken-and-egg problem where the system segments and parameters are dependent.

The above problem was solved by *K*-means[4] and EM algorithm[5]. Those techniques were modified so that they evaluate likelihood of each subsystem through the least -square-minimization. The result supports the hypothesis that the robot controller models a human controller.

II. COM-COP Regulator Model

It is known in humanoid robotics that the relationship between the center of mass (COM) and the center of pressure (COP) highlights the core dynamics of the whole-body motion. The simplified equation of motion is

$$\ddot{y} = \zeta^2 (y - y_Z), \tag{1}$$

where y and y_Z are the lateral positions of COM and COP, respectively, and ζ is the positive system eigenvalue. y_Z is subject to the following inequality:

$$y_{Z\min} \le y_Z \le y_{Z\max}, \tag{2}$$

where $[y_{Z\min}, y_{Z\max}]$ is the lateral supporting region.

Eq. (1) tells that COP works as the control input for COM. Sugihara[1] proposed a picewise-linear regulator as

$$y_Z = \mathrm{sat}\{y + k_1(y - y) + k_2\dot{y}, y_{Z\min}, y_{Z\max}\}, \tag{3}$$

where $\mathrm{sat}\{x,a,b\}$ is a function that saturates x in $[a,b]$. k_1 and k_2 are feedback gains. The left side of Fig. 1 shows the phase portrait of the system in theory. The two red lines segment the space into three subsystems. The right side of Fig. 1 is the loci of measured motion of a human subject[2,3]. It presents a similar flow to the theoretical solution curves.

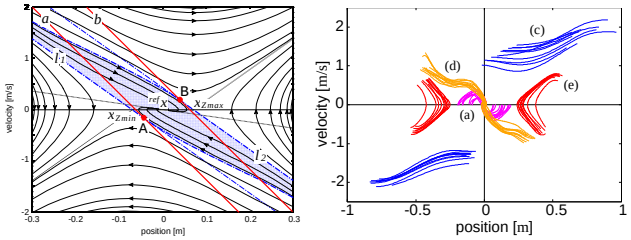

Fig. 1. Phase portrait of COM-COP regulator and measured loci

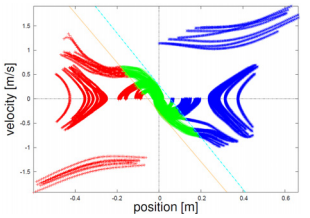

Fig. 2 Identified segments of the piecewise-affine system

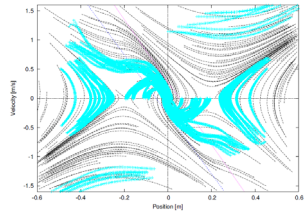

Fig. 3 Solution curves of the identified dynamical system

III. Identification of Piecewise-Affine System

K-means[4] and EM algorithm[5] were used in which the metric was defined by the residual of least-square-minimization such that it enables simultaneous parameter identification and segmentation. The samples on the loci were correctly segmented as Fig. 2 shows, and the solution curves of the identified system in Fig. 3 matches the loci. This mathematically-explicit representation of a controller facilitates understanding what information the human uses and how she enlarges the stabilization performance, which the authors think affects higher behavior synthesis.

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