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HOW COME A MOVING BIPED DOES NOT FALL THE CHALLENGE TO APPLY THEORETICAL STABILITY CONCEPTS

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ABSTRACT

Statements about stability often lack expressiveness due to inaccurate terminology or poor coupling with modelled archetypes. In this article different types of stability and necessary assumptions are recapitulated, and their validity is checked in real systems. Although basic principles of human locomotion can be well explained by simple mathematical models and deeper understanding is gained, more complex models are necessary to verify and improve these theories. The motion we found in human walking as well as in simple walking robots cannot be described by limit cycles. Although they show chaotic motion with regard to kinematic parameters, they maintain the general goals of keeping the center of mass (CoM) above the ground and travelling forward constantly. Most stability concepts cannot answer the basic question of stability, therefore suggestions for more applicable concepts are formulated.

INTRODUCTION

The ultimate goal of measuring stability in humanoid locomotion is to understand how come a moving biped does not fall. The term "stability" by itself is rather fuzzy. Different stabilities are labelled with the same term, although some of them contradict each other. A locally instable walk of a human [1] is denoted as stable, same as a micrometer-periodically walking model [2, 3]. Discussing stability could be sharpened by using proper terminology, but will be diffuse when "stable" remains the final specification.

Stability is a mathematical concept evaluating the ability of a system to cope with disturbances. A number of robotic bipeds walk in a statically stable manner [4]. Other machines [5, 6, 7] and template models [8, 9, 10] are dynamically stable, resembling human walking more closely. In contrast to real systems, underlying equations of motion can be calculated for simple bipedal walking and running models to provide insight regarding basic dynamics and mechanisms [9]. As these equations may be numerically solved with very high accuracy, ideal conditions lead to periodic solutions. Thus, dynamic stability is calculated for models that have an equilibrium point or a limit cycle. Several mathematical stability concepts may be applied [11] and distinguished as periodic stability [e.g. 12], self-stability [e.g. 13] or passive stability [e.g. 14].

As stated by Dingwell et al. [15], maintaining dynamic stability is the fundamental control task of human locomotion. However, to learn about human locomotion from template models, anchors are needed [16]. Major drawbacks of applying stability concepts obtained from computer models not sufficiently anchored are (i) the use of infinitesimally small perturbations to measure stability and (ii) the assumption that bipedal locomotion is a purely periodic motion. The current study queries whether existing stability concepts have the potential to answer the question "How come a moving biped does not fall?".

METHODS

Kinematic data at constant speed walking of one human subject (1m/s) and one bipedal robot (Runbot [17], 0.35m/s), both on treadmills, were acquired by a motion capturing system (Qualisys, 240Hz). The CoM motion was calculated for the human subject [18] and its vertical component was compared with the vertical motion of the stiff robot trunk. Velocities were calculated numerically using Matlab (The Mathworks). Phase plots of both vertical CoM motions for 28 consecutive steps of the human subject and 21 consecutive steps of the robot are shown in Fig. 1.

RESULTS AND DISCUSSION

Although the steady-state motion observed in both systems seems cyclic at first glance, the phase-plots show high variability far beyond infinitesimally small deviations. As presumed steady-state motion is kinematically not purely periodic. Stability con-

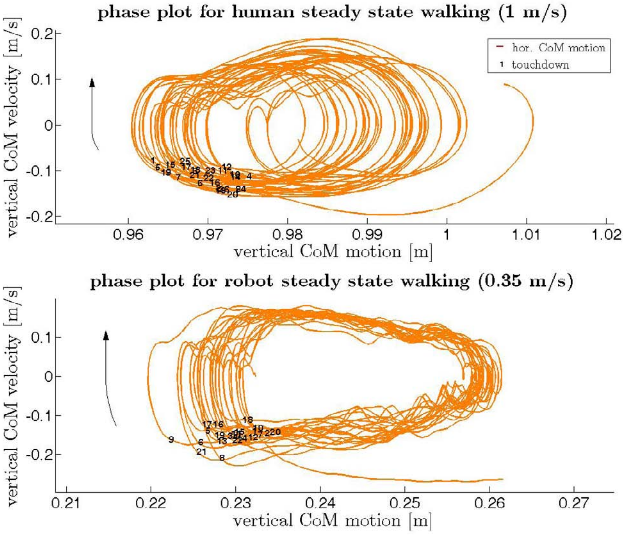

FIGURE 1. VERTICAL COM VELOCITY IS PLOTTED OVER COM MOTION FOR STEADY-STATE WALKING OF A HUMAN SUBJECT AT 1 m/s (TOP) AND A ROBOT AT 0.35 m/s (BOTTOM). THE SEQUENCE OF TOUCHDOWNS IS INDICATED BY NUMBERS.

cepts based on periodic motion and small perturbations are not applicable. Regardless of this kinematic randomness, however, neither the robot nor the human failed to maintain the motion and can be described as dynamically stable.

CONCLUSION

Current concepts of stability measurement and analysis based on periodic motion are not sufficiently anchored in reality and thus lack explanatory power. Considering the effort of never falling and observing the human archetype could lead to a more relaxed definition of stability by taking constructive measures to tolerate falling. A discerning review of present concepts and broad discussions between biomechanists, physicists and engineers is required. Energetic considerations might help to gain deeper insight into system stability without sticking to kinematic periodicity.

The ongoing discussions uncover the need for advanced experimental techniques to evaluate findings from template models in anchors like robot models with comparable means of measurements. Hence, the understanding for mechanical and neuromuscular functions and interactions can be validated.

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