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( 要 旨 )

We humans are bipeds with about two thirds of body mass located on about two thirds of body height above the ground level, so we are an inherently unstable mechanical system, unless a control system is continuously acting. The control of balance, hence, is always a challenge and a side objective in human movements. Any failure in the control of balance may easily lead to an initiation of a fall. The degeneration of the balance control in the elderly and in many pathologies, added to the fact of the increase in our aging population and with increased life expectancy of our elderly, has forced researchers and clinicians to understand more about how the system works and how to quantify its status at any point in time. In this framework two key questions emerge: 1) what is the feasible range of movement for a body to remain balanced while standing, and 2) how good the balance is at a body situation or at every moment during a task.

A feasible region for the control of balance has been proposed previously in the center of mass (CoM) position-velocity plane. This research shows that for a certain individual with given anatomical and mechanical parameters, the feasible movements of the CoM, or more generally the range of states at which the control of balance would be possible, can be analytically found through a mechanical reasoning. This research introduces a subspace of the motion state space, namely the integrated stable subspaces (ISS), dependent on the model's anatomical and strength parameters, and proves that the control of balance is possible all over the ISS. In order to illustrate how the method may be used in practice, the feasible region for a well-known 2-segment mechanical model as well as for a 3-segment one is found using this approach, and is compared to that found by the conventional method. The feasible region found by this method depends on the physical properties of a body including anatomical parameters of a body as well as the torque (control input) constraints. The method works with any arbitrary shape of the control input constraint.

Regarding question (2), a metric to quantify the level of stability at a body situation (state) is the matter. In this research a new measure for postural upright stability is suggested which assigns a value to a body state addressing how possible the control of balance at that state is. The principle is that a bigger stability value should be granted to a state from which a bigger portion of the society will be able to control their balance and not initiating a fall. Using the population's statistical characteristics and taking advantage of the concept of probability, the postural stability at a state is defined as the probability of the balance to be recoverable over the entire population, and called the probability of recovery (PoR). For a

perturbed body state solving the balance recovery problem for a population sample of 600 subjects estimates which portion of them are able to maintain their balance. PoR takes values between zero (0%, no one, low stability) and one (100%, everyone, high stability). It, therefore, describes an attribute of a body state: how possible the control of balance is, or how safe being at that state is. The PoR calculated for a 3-segment body model is shown for all states on a plane, compared to that found using a 2-segment model, and compared to the conventional metric: the margin of stability (MoS). It is shown, for example, that MoS may be very low at a state from which most of the people will be able to easily control their balance.

The new method of finding the feasible range of movements proposed in this research is, in contrast with the conventional approaches, free of iterative numerical calculations, and hence is very fast. A result is, one may easily change the model parameters and follow how the range of feasible movements will be altered, or study the effect of each anatomical and strength parameter in the feasible range of movements.

The postural upright stability that defined in this research shows how probable avoiding a fall initiation is at a body state. It compares the states directly on the basis of success of the primitive balance control strategies, and hence, is capable to represent the stability at a body state by a single scalar quantifying how good the balance is, or its complementary, how likely the loss of balance is. A corollary, for example, is that a perturbation, no matter of what type or how complicated it is, may be transferred to the state space and replaced with a single scalar: PoR, as a function of the response delay.