Dynamic Gait Measure for Biped Walking of Robots and Humans

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ABSTRACT
(Preferred format: 15-minute talk)

Understanding and mimicking human gait is essential for design and control of biped walking robots. The unique characteristic of normal human gait is described as dynamic walking, whereas general human gait is not always dynamic. To study various walking motions, it is important to quantify the different levels of dynamic nature, which have not been addressed in the current literature. In this research, we introduce two formulation approaches of defining Dynamic Gait Measure (DGM) that quantify the dynamic nature of a given biped walking motion.

One approach is to associate the DGM with the gait stability, where the inertia effect is represented in term of the Zero-Moment Point (ZMP) and the ground projection of center of mass (GCOM). From definitions, the main difference between the ZMP and the GCOM is the effect of inertia (assuming gravity is the only externally applied force). Therefore, the distance between the ZMP and the GCOM at each time provides a measure of how dynamic the current gait is. To address the distance over the time duration, the root mean square (RMS) of the distance between ZMP and GCOM is used. Also, to incorporate the relative stability into the measure of dynamicity, the RMS distance of a gait should be compared with that of a static walking for which the GCOM, as well as the ZMP, always exists within the foot support region. Finally, to represent the relative measure of dynamicity for a given gait motion and foot dimension, we define the dimensionless DGM as the ratio of the RMS distances for the given walking and the limiting static walking. In this way, the DGM takes into account the stance foot dimension and the relative threshold between the static and dynamic gaits. From this definition, it can be shown that the DGM is always positive (or zero) and is bounded from above by a parameter K (which can be derived using the system parameters), and can be interpreted according to several cases as follows:

- $DGM = 0$: The ZMP and GCOM are identical at all times. The motion of the system is stationary, or can be regarded as quasi-static.
- $0 < DGM < 1$: The GCOM, as well as the ZMP, stays within the foot support region during the gait. This indicates that the walking is static. The smaller DGM values imply more statically stable than the larger ones.
- $DGM = 1$: The gait motion is marginally static, and its dynamicity is at the border between static and dynamic walking.
- $1 < DGM \leq K$: The GCOM falls outside of the support region at some times, while the ZMP stays within the support region at all times. The larger DGM values imply more dynamic gait than the smaller ones. In other words, the existence of GCOM outside of the foot support region during longer duration or the larger distance between the ZMP and GCOM will result in larger DGM. According to the inverted pendulum model analogy, larger distance between the GCOM and the ankle joint for a given actuation capacity indicates higher tendency to fall at the time instant. Therefore, the DGM also indicates a time-global measure of instability during a gait.

Another approach of defining the DGM is based on the phase plane analyses where the balanced state domain of the system is constructed and the phase trajectory of the biped walking is plotted. The lengths of the phase trajectory segments that are within and outside of the balanced state domain are

calculated as line integrals along the time, respectively, and the ratio of the two lengths are used to formulate the DGM.

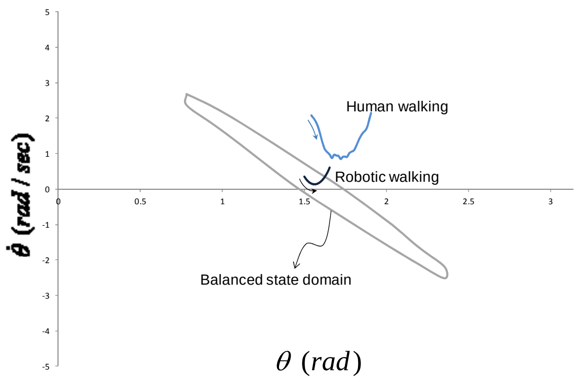

Figure: Balanced state domain and phase trajectories for human and robotic walking motions (only single support phase is shown).

Using the proposed approaches, both human and robotic walking motions with various stance foot dimensions are analyzed and compared. The DGM results verify the dynamic nature of normal human walking with anthropomorphic foot dimension. In general, the DGMs for human walking are greater than those for robotic walking. The resulting DGMs also demonstrate their dependence on the stance foot dimension as well as the walking motion. The proposed DGMs provide a single measure of the dynamic nature of a given biped walking motion.

This research will provide valuable insights in exploring and understanding fundamental principles of human biped walking and their applications in engineering and clinics. The proposed measures can also be used as criteria for design and control of efficient walking robots.

Key words: dynamic gait measure, Zero-Moment Point (ZMP), phase trajectory.