A State Space Perspective of Dynamic Torso Stability

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ABSTRACT

Low back pain is often associated with torso instability that may result in potentially injurious motion. Yet little information is available on the dynamic stability of the spine and core musculature. In previous experimental studies stability diffusion analysis [1] and the time series averaged finite time Lyapunov exponent (FTLE) [2] were calculated to determine the local dynamic stability of the system. However, additional information can be extracted from the time series data. Rather than averaging the Lyapunov exponents over state space to obtain a single scalar value (traditional method), one can generate a FTLE field. This field quantifies the expansion rate at different locations in state space and may be used to locate separatrices demarking the boundary between stable and unstable trajectories.

In order to improve the fundamental understand this medical condition, mathematical models were developed based on seated torso stability experiments. Lagrangian coherent structures (LCS), ridges in the state space distribution of the FTLE field, were used to locate basins of stability. We demonstrate how LCS can be found from time series data without knowledge of the complete vector field as required by previous approaches [3]. As a result, this approach was shown to be well suited for biomechanics experiments where often only time series data is available. Furthermore, since LCS are robust to noise this approach is even more attractive for use with experimental data analysis where noise sensitivity is an important issue. We also illustrate how morphing was used to identify stable PD control gain parameters for the forward dynamic simulation that could not otherwise be determined. Finally, the basins of stability for the models and locations of the equilibrium manifolds will be presented.

The basin of stability in state space provides a richer understanding of the system dynamics than a single scalar value (previous methods). The boundary, or recovery envelope, could be used in conjunction with sway data to define new measures of individual fall risk, e.g., the average distance of an individual's state from the boundary. In general, we believe the method demonstrated in this study provides a fruitful approach for extracting additional information from noisy experimental data, namely boundaries between qualitatively different kinds of motion.

REFERENCES

1. Tanaka, M.L. and K.P. Granata, Methods & Nonlinear Analysis for Measuring Torso Stability, in ASCE 18th Engineering Mechanics Division Conference. 2007: Blacksburg, VA.
2. Shadden, S.C., F. Lekien, and J.E. Marsden, Definition and properties of Lagrangian coherent structures from finite-time Lyapunov exponents in two-dimensional aperiodic flows. Physica D-Nonlinear Phenomena, 2005. **212**(3-4): p. 271-304.