TIME DOMAIN ANALYSIS OF LOCAL DYNAMIC STABILITY MAY BE USEFUL IN PREDICTING A CRITICAL EVENT BEFORE IT OCCURS

Martin L. Tanaka and Chaoke Dong

School of Engineering and Technology
Western Carolina University
Cullowhee, North Carolina, USA

INTRODUCTION

Low back pain is a common medical problem that affects 4 out of every 5 people some time during their life. Idiopathic low back pain has been associated with torso instability. One method used to quantify local dynamic stability is to calculate the maximum finite time Lyapunov exponent. The Lyapunov exponent describes how quickly two initially close points diverge in state space. Previous researchers have calculated the Lyapunov exponents and averaged them to obtain a single scaler value [1]. This value was used it to evaluate if deterministic chaos existed in a system. Others have plotted the Lyapunov exponent in state space to find regions of stability and located boundaries between stable and unstable regions [2]. However, we are not aware of any researchers who have calculated the Lyapunov exponent and examined how it changes within the time domain. The focus of this research was to determine how the Lyapunov exponent changes in the time domain as it approaches a critical transition (i.e. falling, in our case).

METHODS

The initial investigation consisted of thorough testing of two participants. The study was approved by the Institutional Review Board (IRB) and participants signed informed consent prior to beginning the study. Each participant balanced on an unstable sitting apparatus capable of attaining large deflection angles (Figure 1). Participants maintained balance until falling into a foam padded safety frame. Roll, pitch and yaw angles were collected using a gyroscopic sensor and a custom LabView program during the balancing and falling portions of the trail. Data was imported in to Matlab to generate plots and calculate the Lyapunov exponent. Participants repeated the trial multiple times (55 for participant 1) so that a large data set could be establish for analysis. Trials were performed in multiple sets over several days in order to avoid fatigue.

Figure 1: Experimental configuration. Participant balances on a kneeling chair in the center of a foam padded safety frame.

RESULTS

Figure 2 shows the results of a typical set of torso balancing trials. The participant balances around zero degrees until falling backwards (negative angle) or forwards. The time of zero indicates the beginning of data collection after initial balance is attained.

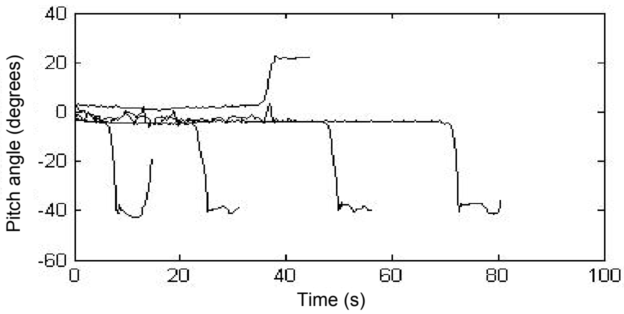

Figure 2: Pitch angle remained close to zero prior to falling.

In order to compare the behavior over multiple trials, the zero reference time was changed to the midpoint of the fall. Using this reference negative time indicates the time prior to falling and positive time indicates the time elapsed after the fall. All trials were aligned based on this new time reference and the results are shown below (Figure 3).

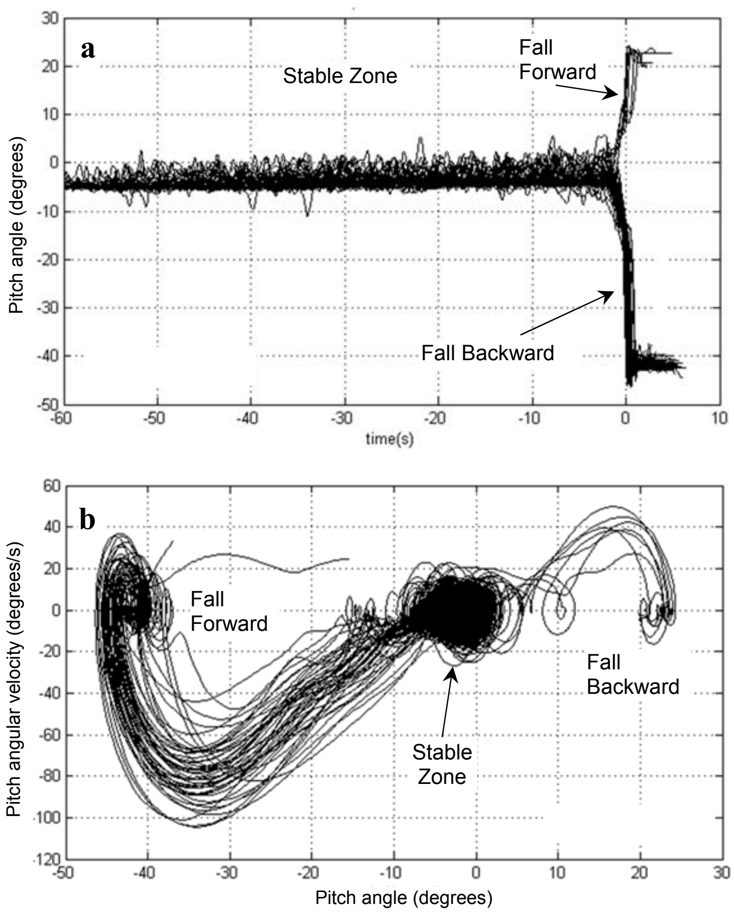

Figure 3: Time domain (a) and state space (b) representation of 55 trials by a single study participant.

The Lyapunov exponent for each data point in the time domain was calculated and the average value for 55 trials is shown (Figure 4). The central line (blue) is the mean value and the upper (green) and lower (red) lines indicate +/- 1 standard deviation, respectively. Several zones are noticeable in this time domain plot of the Lyapunov exponent. The first is the stable zone where the Lyapunov exponent undulates around 105 while the participant maintains balance. The second is the transition zones, where a small peak is observed. This peak may be an indicator that the test subject is beginning to lose stability. Next is the falling zones where the Lyapunov exponent sharply drops from about 95 to 47. Motion during falling is more consistent behavior and results in a lower Lyapunov exponent. Within the post fall zone the participant impacts the safety frame, bounces off, and then comes to rest. This causes a spike in the Lyapunov exponent which then decreases.

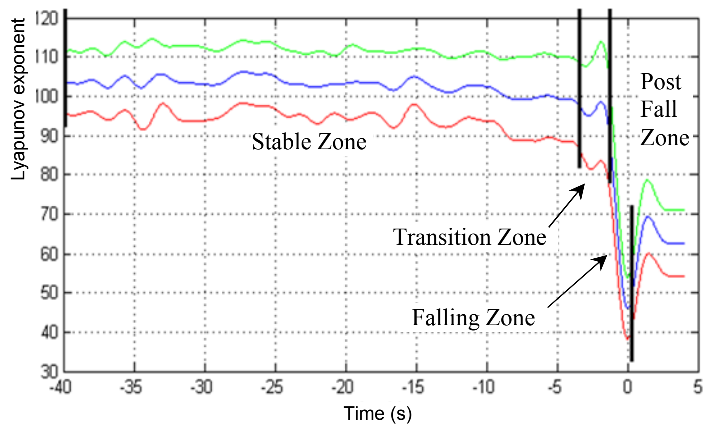

Figure 4: Average Lyapunov exponent (blue) for 55 trials. Note the 4 regions, stable, transition, falling, and post fall.

DISCUSSION

A key discovery of this research was that the Lyapunov exponent changed over time as it approached the critical event (the fall). The standard deviation bands show the trends to be consistent over multiple trials. The small peak observed in the transition region was observed just prior to the fall. Further investigation is needed to determine if this is a real effect or an artifact.

Tracking the Lyapunov exponent in the time domain may be useful as an indicator to predict a future event. This approach not only can be used for this research, but is also generalizable to other dynamic systems that have critical events. The ability to predict a future event *prior to its occurrence* may be used as a warning so that preventative action may be taken to avoid the occurrence or minimize potential negative effects. This is similar to an air bag system that detects high accelerations and uses this information to inflate the bag to protect the occupants during a crash.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Rosenstein, M. T., Collins, J. J., and Deluca, C. J., 1993, "A Practical Method for Calculating Largest Lyapunov Exponents from Small Data Sets," Physica D, 65(1-2), pp. 117-134.

[2] Ross, S. D., Tanaka, M. L., and Senatore, C., 2010, "Detecting dynamical boundaries from kinematic data in biomechanics," Chaos, 20(1), p. 017507.