# SEGMENTATION OF PERIODIC BIOMECHANICAL SIGNALS BY JOINT SPACE DISTANCE CRITERION

## MOTIVATION

An automated signal segmentation procedure based on cycle period can greatly reduce the time and error involved in the treatment of voluminous data generated in experiments of periodic activities such as walking. Most of the available methods[1] are application specific and based on single joint signals. Here we introduce a dynamic systems theory based approach to period computation that is theoretically principled, completely general, and is robust to noise and other errors that affect existing approaches. In addition, the method presents significant convenience in visual period estimation, as we see below.

## METHODS

The states of a periodic system repeat themselves after each fixed interval of time. The shortest such interval is called the *time period* of the system. The inter-segmental joint angles and velocities may constitute the states of locomotion.

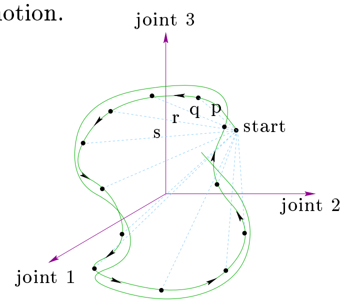


Figure 1: Walk trajectory in 3D joint-space.

At each sampling interval we record the joint angles of a walking human subject. The "joint space," is a multi-dimensional space (equal to the number of joint angles) where each point represents the configuration of the subject at an instant. As the person walks, the "representative point" in the joint space also moves, and the shape of its trajectory characterizes the movement. Fig. 1 sketches a trajectory in a 3-dimensional joint-space. Whereas for a perfectly periodic system the trajectory retraces itself after each cycle, in a more realistic situation it will pass by close to the starting point after each period. This is the crucial idea which we employ to determine the cycle period. Starting from a point ("start" in Fig. 1) in the joint space we calculate the straight-line distances ($p$, $q$, $r$, $s$ ...) of the subsequent trajectory points. The end of the period is is indicated when this multidimensional distance reaches a minimum value.

The Euclidean distance from the $i^{th}$ point to the $j^{th}$ point on this cyclic trajectory, $dist(i,j)$, is calculated as :

$$dist(i,j) \quad = \quad \sqrt{(joint1(j) - joint1(i))^2 + (joint2(j) - joint2(i))^2 + (joint3(j) - joint3(i))^2 + \dots} \qquad (1)$$

The computed distances are appropriately scaled to emphasize the minima in the curves.

## RESULTS

We use unfiltered locomotion data for 10 seconds (2000 data collection intervals) from 10 inter-segmental angles, which include upper and lower extremities, of a subject to calculate joint space distance. The figures below show *dist(i,j)* plotted over data intervals, each figure beginning at a different "start" point in the gait cycle. The presence of repetitive steep minima is visually prominent and should be compared with typical single joint plots. The positions of the minima are robust against the noise in the unfiltered data.

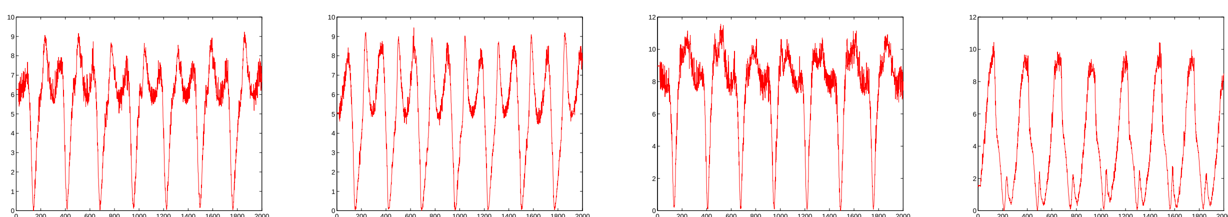

Figure 2: Plots of joint space distance with respect to sampling interval, from different "start" points.

A Fourier power spectrum analysis may give us the averaged predominant frequency content of the signal; for the current dataset it is 0.7Hz.

## DISCUSSION

Recall that we did not consider the complete state vector of locomotion – we ignored the velocity data. Thus we may encounter situations (e.g., near intersecting trajectories) where the *dist(i,j)* plot has multiple minima within a cycle, as shown in Fig. 2, extreme right. Such a situation may be rectified by incorporating the velocity data. The starting point for the distance calculation is currently chosen arbitrarily and may affect the relative ease with which the minima are recognized.

# References


[1] E. Cordier. Automatic method for cycle extraction and segmentation in human gait kinematic data. In *Proc. XVIth Congress of the ISB, Tokyo*, August, 1997.