Kinematic quantification of gait symmetry basesd on bilateral cyclograms

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Introduction

Symmetry is considered to be an important indicator of healthy gait and a lack of symmetry the effect of various pathologies. Information on gait symmetry can be instrumental in clinical diagnosis, decision-making and for tracking the progress of rehabilitation procedures.

We introduce a system of gait symmetry measures that are derived from the *geometric properties of bilateral cyclograms* (also called angle-angle diagrams). The symmetry measures are simple, physically meaningful, objective, reliable and well suited for statistical study. We compute the symmetry measures for gaits in both normal and hemiparetic subjects and demonstrate how they can be used to characterize normal gait and identify and quantify gait asymmetry.

What is symmetry?

Symmetry is generally referred to as the similarity of movement between the two sides of the body. Here we focus on the similarity of leg movement pattern during gait.

Symmetry is one of the first casualties of a gait pathology. Gait symmetry can be compromised due to various factors such as limb asymmetry, injury, use of prosthesis, stroke, cerebral palsy and other mobility-affecting diseases.

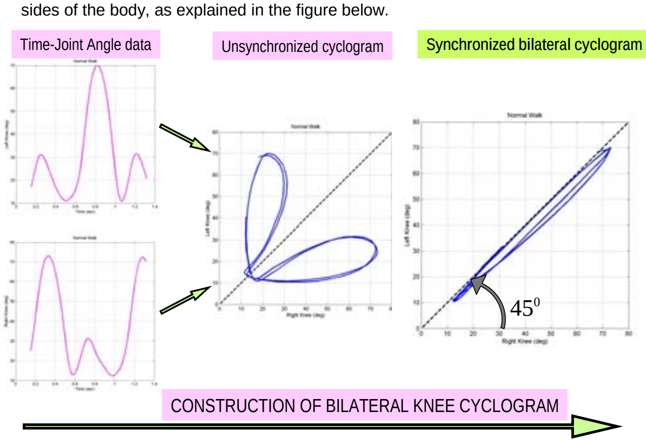
Our current approach is *kinematic*. It is based on the symmetry of joint angle trajectory. We compare the evolution of a single joint with that of its contra-lateral counterpart.

Bilateral Cyclograms

Symmetry can be measured through discrete variables as well as through the analysis of time-signal curves. Our strong favorite is the cyclogram (Grieve, 1968; Hershler and Milner, 1980).

Traditional cyclograms are closed trajectories generated by simultaneously plotting two (or more) joint variables. In gait study the easily identifiable planar hip-knee cyclograms have received the most attention (Goswami, 1998).

We introduce *bilateral cyclograms* obtained from the <u>*same*</u> joint from two sides of the body, as explained in the figure below.



For a perfectly symmetric gait, the synchronized twin trajectories from corresponding joints should be identical. In other words, the bilateral cyclogram should lie entirely on a 45° *symmetry line*. In reality, no gait is perfectly symmetric. Hence the cyclogram deviates from the symmetry line, as seen above in the RHS plot.

Methods

The nature and magnitude of the cyclogram's deviation from the symmetry line is a measure of asymmetry in the gait. We mathematically measure these deviations to obtain a quantification of gait symmetry.

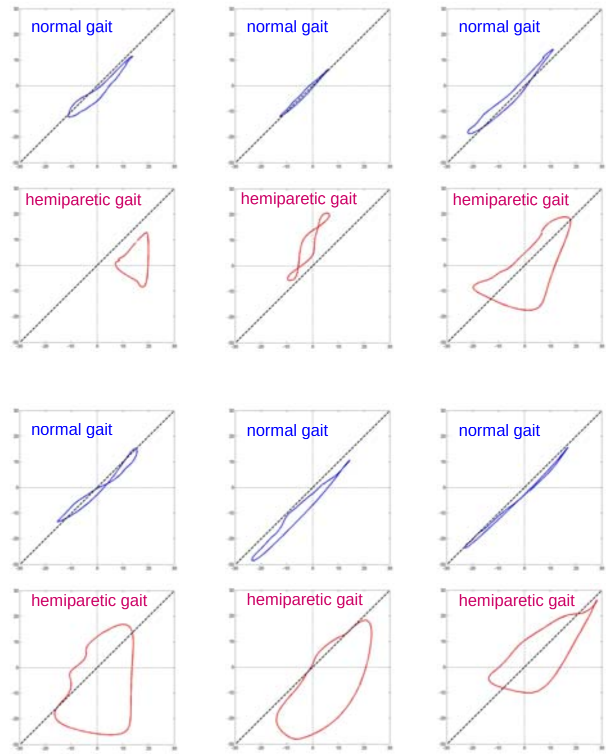
For this purpose a number of geometric parameters descriptive of the symmetry line may be utilized. We will currently focus on three parameters:

1) *Cyclogram **area**:* Computed with simple numerical techniques.

2) *Cyclogram **orientation**:* Orientation of a planar geometric entity is defined as the angle between the positive abscissa and the line of least second-order moment.

3) ***Minimum moment** of cyclogram*: We make a physical analogy of the cyclogram with a thin polygonal wire loop having uniform mass distribution along its length. The two principal second-order moments are the moments of inertia of the wire contour along its two principal directions. The principal directions, obtained by eigenvalue analysis of the moment refer to the directions in which the contour is the most and the least oblong.

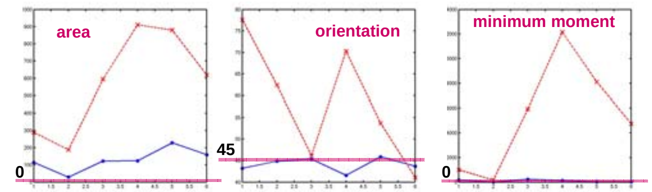
The symmetry line has zero area, 45° orientation and zero minimum geometric moment.



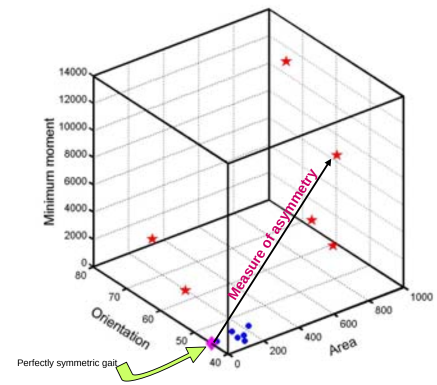
Right hip VS left hip bilateral cyclograms for six **hemiparetic** (red) and six speed-matched **normal** (blue) subjects in slow walk. The 45° symmetry line is shown dotted.

Results

Bilateral cyclogram for the <u>*perfectly symmetric*</u> gait should have zero area, 45° orientation and zero minimum geometric moment. Deviation from this is the measure of asymmetry.



Area, orientation and minimum moment magnitude of bilateral hip cyclograms plotted for gaits of 6 **normal** (blue) and 6 **hemiparetic** (red) subjects.



Area, orientation and minimum moment plotted for 6 **normal** (●) and 6 **hemiparetic** (★) subjects. The perfectly symmetric gait (0,45,0) is plotted with a ♦. A measure of asymmetry is the distance between the ♦ to a representative gait data point ● or ★.

Discussion and future work

Likewise for the other symmetry measures, the presented technique is also sensitive, especially for the area measure, to the precision of synchronization of the two signals.

The method is not restricted to gait study and can also be used to study, say, arm swing symmetry. Gait involves a multitude of joints and so does the manifestation of gait asymmetry. One can envisage analyzing the coordinated evolution of multiple joints as the key to symmetry calculation. Although due to high dimensionality these techniques are not graphically presentable, they will be of higher information content and will better characterize gait symmetry. This is planned work for the future. We are also exploring the use of phase diagrams to incorporate velocity asymmetry information in addition to asymmetry in angular position.

An improvement to the presented method will be to use normalized units. With normalization, the numerical values of the individual symmetry quantifiers such as the cyclogram area will have a more fundamental meaning.

Acknowledgements

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