MOMENT-BASED PARAMETERIZATION OF CYCLOGRAMS OF SLOPE-WALKING

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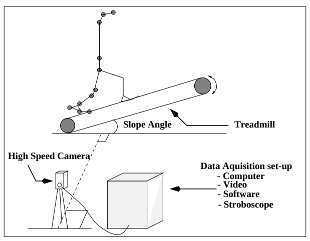
1 MOTIVATION

The problem under study is the moment-based parameterization of a series of gradually evolving cyclograms. The cyclograms correspond to natural human walk on a variable-inclination treadmill with slope varying from $-13°$ to $+13°$ at each $1°$ interval. Parameterization of cyclograms has several useful applications including the diagnosis of pathological gait. For this study we consider the planar hip angle/knee angle cyclograms although the described method is fairly general in nature and may be used without restriction for any closed curve such as the phase diagrams and the moment-angle diagrams. Moreover, the method can be extended to higher dimensions and thus we can treat cyclograms involving three or more joint angles.

Moment-based identification of physical objects is a topic of active research in the field of pattern recognition. We perform the necessary adaptations of these techniques to use them in biomechanics.

2 METHODS

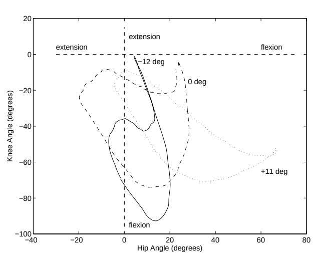


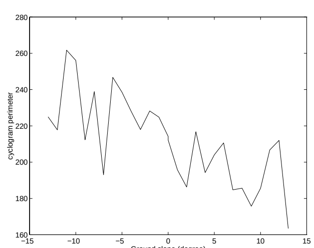
We collected sagittal plane position data of retro-reflective markers attached to the traditionally used bony landmarks of two healthy treadmill-habituated male subjects with a video camera. The treadmill speed was adjusted so that the subjects could walk with their natural gaits. After each run, consisting of several datasets from the same slope, the treadmill inclination was changed without any pre-specified order to prevent any anticipatory gait by the subjects. The marker position data were subsequently smoothed using a Butterworth filter and the inter-segmental angles were extracted from them.

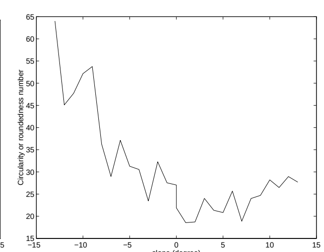
We consider that the closed-loop cyclograms are physically analogous to thin wire loops with uniform mass distribution. The analogy is justified in [1]. The two-dimensional moments of order $(p+q)$ of a curve of length L is expressed as [3], $M_{pq} = \int_0^L x^p y^q \, dl$, where the curve is represented in the xy-plane. Since, in practice, the cyclograms are constructed from discrete data points, the above equations become summations rather than integrals. It can be shown that for the cyclograms the perimeter $P = M_{00}$, the position of the center of gravity $x_{CG} = \frac{M_{10}}{M_{00}}$, $y_{CG} = \frac{M_{01}}{M_{00}}$, and the orientation are obtained from M_{20}, M_{11} and M_{02}. Many other parameters can be calculated as well from the moments[1].

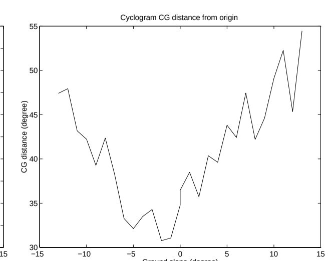
3 RESULTS

The evolution of several gait features were studied for parameterization. A representative of the results are shown in the following set of figures. The first figure exhibits the substantial change in the forms of the









hip-knee cyclograms. The cyclograms in the figure correspond to $-12°$, level walk, and $+11°$ slopes. The results are similar to those found by [4]. The cyclogram perimeter (in degree) has a clear decreasing trend as can be seen from the second figure. The next figure shows the circularity factor or the roundedness criterion [2] as a function of slope. The fourth figure characterizes the evolution of the distance of the CG of the cyclograms with the ground slope.

4 DISCUSSION

This study provides us with a straightforward route to the parameterization of slope walking gait. We may start, for instance, by fitting the above curves with linear, piecewise linear or quadratic functions. Please note that the significant fluctuations in the plots are partly due to the fact that the walk cycles were not extracted with any signal processing technique but were obtained visually from smoothed data. Appropriate segmentation techniques are expected to improve the results.

References

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[3] X. Jiang and H. Bunke. Simple and fast computation of moments. *Pattern Recognition*, 24(8):801–806, 1991.

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