A biologically inspired latent space for gait parameterization

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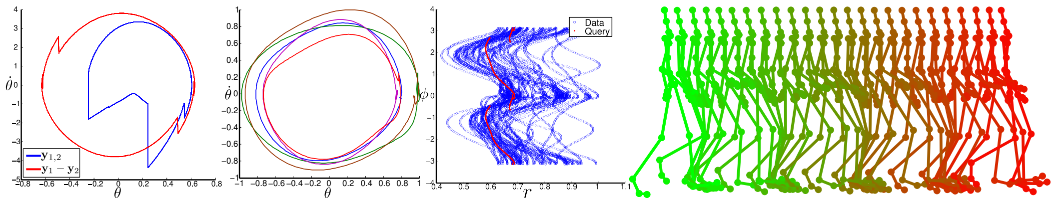

(a) *Phase space of the passive walking model (used as a query)* **(b)** *Phase space of 5 real walking cycles* **(c)** *Latent space query* **(d)** *Motion query result*

Figure 1: *Our latent space is suitable for mapping low dimensional simulations of human gait into a motion database.*

Introduction

The problem of character locomotion synthesis is notorious for its high dimensionality and the nonlinear relationship between dimensions. However, many human motion activities lie intrinsically on low dimensional manifolds [Safonova et al. 2004] leading to significant data redundancy. Linear and non–linear methods for dimension reduction have been applied to the problem, but none of the existing approaches for dimensional reduction provide a physically–justified explanation for selected dimensions, instead they use general methods which employ numerical error analysis.

[Full and Koditschek 1999] theorize that all biological motion is governed by low dimensional **templates**: the simplest possible model required to exhibit a desired action. While the motion we observe may appear complex and non–linear, the body is still attempting to adhere as closely as possible to this low dimensional template. The cyclical behavior of locomotion has been observed in both biology and robotics disciplines, and is a guiding principle of dynamic system design (see Figure 1b). We propose that this cycle is the template to which human locomotion is attempting to adhere, implying that a polar representation of this space will yield a feature rich latent space.

Dynamic models used to drive energy efficient robots do not rely on motion capture data or statistical methods to derive motion. These models are physics based and are able to synthesize motion for unpredicted environmental conditions. However, due to the numerical complexity in analyzing these systems they are typically very simple, seldom incorporating an upper body, and are normally simulated in only the 2D sagital plane to remove problems associated with the de–stabilizing effect of side swing behavior.

We use a dynamic model to drive a virtual character by a latent space mapping into a database of captured motion states. The mapping is achieved using standard statistical and point–based methods, and results in motion that enriches the dynamic walking motion with plausible upper body, ankle and knee animations, and yielding motion that is generally smooth and natural looking.

Method and Results

We define θ_i to be the angle between the vertical and the thigh of leg i, so the state variable for leg $i = 1, 2$ as $\mathbf{y}_i = \left\{\theta_i, \dot{\theta}_i\right\}$. We define our reduced dimensional mapping space for both legs as $\hat{\mathbf{y}} = \{r, \phi\}$ where r and ϕ are the coordinates of $(\mathbf{y}_1 - \mathbf{y}_2)$ in polar coordinates (see Figure 1a).

In Figure 1b it is clear from 5 extracted steps from our motion database that gait generally conforms with this cyclical behaviour. A polar representation is therefore ideal because of *the small variance of r for each step* — if the data is incomplete, a fixed r and an increasing ϕ will still result in a plausible walking motion. General methods are less suitable because they do not exploit biological meaning.

The compass gait model is one of the simplest dynamic models for human locomotion. Its energy efficiency results in adaptive locomotion behavior that is natural looking. We adapt our mechanical model from [Chen 2007], and the [Matsuoka 1985] neural oscillator is used as a controller. The structural stability of the coupled dynamic system is enhanced by *entrainment*: the phenomenon whereby two coupled oscillating systems, with different periods when they function independently, assume the same period.

For a query, nearby motion states must be queried from with the latent space and the results blended to form the query result for a particular frame. We have implemented three methods to perform motion querying: **K-Nearest Neighbors** (fast, no coherence, not smooth), **Iterative Closest Point** (exploits coherence, prone to drift) and **Moving Least Squares projection** (exploits coherence, smooth, slowest).

In Figure 1c, steps from 46 individuals are extracted to form the database (data from the publicly available CMU motion database). Note the discontinuities in the query data (in red) resulting from knee locking and ground impact. Results of the resulting motion by blending the MLS projections of the query point onto the n-nearest walking motions are shown in Figure 1d. A standard smoothing filter was applied to correct the discontinuity errors resulting from the passive model. Effectively the ankle, knee and upper body motion is generated with our method.

References

CHEN, V. F. H. 2007. *Passive dynamic walking with knees: A point foot model*. Master's thesis, Massachusetts Institute of Technology.

FULL, R. J., AND KODITSCHEK, D. E. 1999. Templates and anchors: neuromechanical hypotheses of legged locomotion on land. *Journal of Experimental Biology 202*, 23, 3325–3332.

MATSUOKA, K. 1985. Sustained oscillations generated by mutually inhibiting neurons with adaptation. *Biological Cybernetics 52*, 1, 345–353.

SAFONOVA, A., HODGINS, J. K., AND POLLARD, N. S. 2004. Synthesizing physically realistic human motion in low-dimensional, behavior-specific spaces. In *ACM SIGGRAPH 2004 Papers*, ACM, New York, NY, USA, SIGGRAPH '04, 514–521.

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