The Navi Activity Monitor:
On Using Kinematic Data to Humanize Computer Music

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Abstract
A hardware sensor and analysis toolkit is developed to track the human body's natural cadence behavior during rhythmic physical activity. Motivated by previous work employing kinematic models to describe expressive timing in music performance, we investigate the use of kinematic data to humanize computer music.

Keywords: Musical kinematics, expressive tempo, machine music.

1. Introduction
It is inherently natural and fundamentally human to relate music and movement. A considerable amount of musical terminology draws directly from concepts of physical motion, and dance is a significant, culturally universal component predating recorded history. As a global society, we have expanded upon the ways in which people use and interact with music in daily life, with particular emphasis regarding movement and rhythm. Significant research in the field of music therapy has documented the potential benefits of rhythmic cueing [1], and exercise sport science has investigated the psychological impact of music on ratings of perceived exertion during physical activity [2]. However, while there is overwhelming observational evidence of a relationship between music and movement, no unifying theory exists. Previous efforts attempt to establish the nature of this relationship by modelling expressive timing, in particular the *ritardando*, of music performance using computational models.

Kronman and Sundberg (1987) proposed that a musical *ritard* is "an allusion to a physical deceleration," comparing the *ritards* of 24 classical performances with cadence data of runners coming to a standstill [3]. This concept of a kinematic model is further investigated by Friberg and Sundberg (1999) to "link locomotion to music performance," ultimately concluding that *ritardandi* is best expressed as a constant braking force [4]. Alternatively, it is suggested that a blind kinematic model is insufficient to adequately characterize expressive tempo, neglecting contextually relevant musical elements, and Honing (2005) instead proposes a perception-based model [5]. Despite these disagreements, statistical analysis of MIDI performance data by Das et al. (2000) supports the concept of musical kinematics but identifies nonlinear behavior, providing rationale for previous results [6].

Given prior evidence suggesting the intrinsic connection between locomotion and musical expression, a system is proposed to further explore these claims and to generate expressive timing data for compositional applications. Cadence data is collected from unconstrained, free-field runners and analyzed using principles of tempo induction to describe natural tempo evolution during rhythmic physical activity. This information is then mapped to computer music as tempo automation to simulate a more "human performance."

2. Cadence Analysis
Considering the human body in motion as a dynamic mechanical system, it is intuitive to assume that there is an optimal frequency at which the system naturally resonates. To characterize this data, we developed a hardware interface and software analysis toolkit.

2.1 The Navi Activity Monitor
Whereas previous research observing running cadence was restrictive in terms of means and facilities (e.g., limited to a treadmill), a noninvasive sensor was developed to collect physical movement data in natural environments. The Navi Activity Monitor (Figure 1) records tri-axial accelerometer data at a sampling rate of approximately 450 Hz. The design generalizes orientation by resolving the Cartesian acceleration components as a single magnitude vector. Data can be collected by simply carrying the sensor on one's person in a consistent manner, although placement on the torso or waist was determined to be optimal, in agreement with kinematic literature. It is important to note that Navi allows direct estimation of periodicities in movement, rather than implicitly via impact detection, expanding its potential application to all forms of rhythmic motion (running, cycling, dancing, etc.).

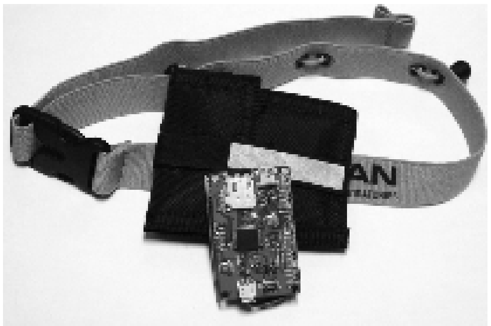

Figure 1 – The Navi Activity Monitor

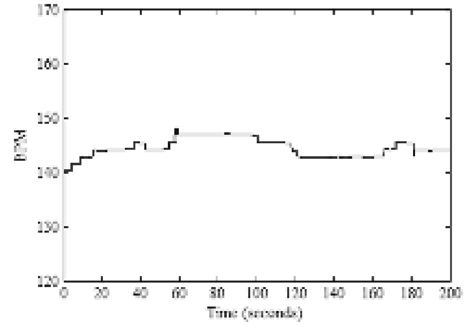

Figure 2 – Kinematic Tempo Curve

2.2 Tempo Induction

Acceleration data collected in the course of a run is processed similarly to the tempo induction of acoustic musical signals. The algorithm developed essentially follows [7], with some notable modifications. Most importantly, the comb-filter bank, used as a model of human rhythm perception, is adjusted to mimic instantaneous tempo estimation. This is achieved by implementing a normalized, variable-length, sliding integrator over each oscillator corresponding to its lag period, effectively acting as tempo memory. At an instant in time, each parallel oscillator maintains an energy that correlates to the salience of its lag period, or inversely, tempo. The highest concentration of energy is taken to be the most salient tempo percept at that instant, and the center of mass is computed over adjacent oscillators based on documented just noticeable differences of tempo fluctuation. An example of a resulting tempo curve for a three-minute jog is shown in Figure 2.

3. Humanizing Computer Music

Machine performance of computer music is often criticized for "robotic" playback. Attempts to address this issue mainly include random, minute inaccuracies in note onsets to mimic human timing imperfections, but the results have met with marginal satisfaction. We instead adopt the kinematic-inspired approach of mapping tempo curves of running data, motivated by previous research in models of expressive timing to further investigate the issue.

In this analysis-by-synthesis methodology, we aim to provide further insight into the kinematic model of expressive timing in music and investigate the impact on computer music. To evaluate the validity of this method, we propose a Turing test of musical expression by synthesizing musical excerpts that represent 4 groups:

i. machine performer, machine clock
ii. machine performer, human clock
iii. human performer, machine clock
iv. human performer, human clock

Through these conditions, we shall investigate under which conditions human listeners believe they are listening to a human or machine performance.

4. Discussion

Currently, the work proposed is still in progress and must undergo a series of listening tests. Special consideration will need to be given to the level of musicianship for each test subject, as it is expected highly trained musicians will exhibit greater sensitivity to not only timing fluctuations, but also the musical appropriateness of such events.

Our system determines a runner's resonant frequency to automatically compile a suitable music playlist by directly analyzing acoustic data. The central focus of that system is the synchronization of movements to music, and the same principles can be applied in the opposite direction to explore the relationship between musical timing and locomotion. Through the analysis of kinematic data, the resulting tempo maps may help produce temporally realistic computer music.

References

[1] M. Thaut, et al. "Effect of rhythmic auditory cuing on temporal stride parameters and EMG patterns in normal gait." *Journal of Neurologic Rehabilitation,* vol. 6, no. 4, pp. 185-190, 1992.

[2] H. Mohammadzadeh, et al. "The effects of music on the perceived exertion rate and performance of trained and untrained individuals during progressive exercise." *Physical Education and Sport,* vol. 6, no. 1, pp. 67-74, 2008.

[3] U. Kronman and J. Sundberg, "Is the musical ritard an allusion to physical motion?" *Action and Perception in Rhythm and Music*, The Royal Swedish Academy of Music, no. 55, pp. 57-68, 1987.

[4] A. Fribeg and J. Sundberg, "Does music performance allude to locomotion? A model of final *ritardandi* derived from measurements of stopping runners," *J. Acoust. Soc. Am.,* vol. 105, no. 3, pp. 1469-1484, 1999.

[5] H. Honing, "Is there a perception-based alternative to kinematic models of *tempo rubato*," *Music Perception*, vol. 23, no. 1, pp. 79-85, 2005.

[6] M. Das, et al. "Motion curves in music: Statistical Analysis of MIDI data," *Proc 25th EUROMICRO Conference*, vol. 2, pp. 13-19, 1999.

[7] E. Scheirer, "Tempo and beat analysis of acoustical musical signals," *J. Acoust. Soc. Am.,* vol. 103, no. 1, pp. 588-601, 1998.