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

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Abstract

Motivated by previous work aimed at developing mathematical models to describe expressive timing in music, and specifically the final *ritardandi*, using measured kinematic data, we further investigate the linkage of locomotion and timing in music. The natural running behavior of four subjects is measured with a wearable sensor prototype and analyzed to create normalized tempo curves. The resulting curves are then used to modulate the final *ritard* of MIDI scores, which are also performed by an expert musician. A Turing-inspired listening test is conducted to observe a human listener's ability to determine the nature of the performer.

Keywords: Musical kinematics, expressive tempo, machine music.

1. Introduction

It is inherently natural and fundamentally human to relate music and movement [1]. 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. Considerable research in the field of music therapy has documented the potential benefits of rhythmic cueing [2]. However, while there is 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].

Given prior evidence in support of a connection between locomotion and musical timing, a system is proposed to further explore these claims and to generate expressive timing data for compositional applications. Cadence data is collected from free-field running and analyzed 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 agrees with intuition that there is an optimal frequency at which the system naturally resonates. To measure this behavior, 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, wearable 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 500 Hz. The design generalizes orientation by resolving the Cartesian acceleration components as a single magnitude vector. For this experiment, four subjects completed six 50-yard running trials, where the subject slowed from a run to a walking pace over the last 15 yards. In keeping with music therapy research, each subject was instructed to maintain an initial pace approximately equal to his or her resonant step frequency.

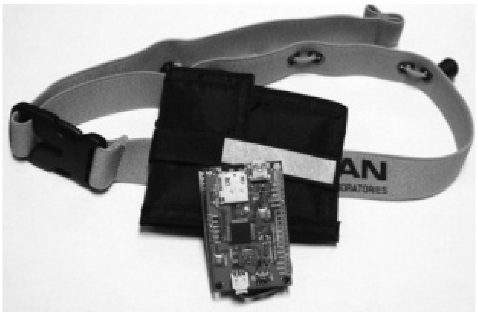

Figure 1. The Navi Activity Monitor

2.2 Tempo Induction

Cadence data collected in the course of a run is processed similarly to the tempo induction of acoustic musical signals [6]. This is significant in so far as creating a uniform, automated mechanism to facilitate the derivation of tempo curves, as well as incorporating a sense of momentum.

3. Humanizing Computer Music

Machine performance of computer music is often anecdotally described as being "inhuman." While potentially present throughout the duration of a piece, it may become particularly apparent in the final *ritard*. Common mechanisms in computer music aim to computationally model observed human behavior with the purpose of achieve the perception of a human performer. Rather than modeling this behavior, the direct analysis of running cadence is used to synthesize the final *ritard*.

In this analysis-by-synthesis methodology, the MIDI Toolbox [7] is used to facilitate the manipulation of note onsets in time. In this approach, there are two significant elements that must be considered, and subsequently constrained. First, an unrealistic note velocity curve can serve as immediate cues to a human listener of an artificial performance. Also, the musical context in which the *ritard* occurs is important. The aim here, however, is to further investigate locomotion as an inspiration for a particular musical behavior, and not the loftier goal of machine musicianship. For these reasons, the note velocities and initial conditions at the start of the *ritard* are taken from the expert musician

Given that the primary goal is to attain human-like behavior, a Turing-inspired experiment is conducted. Three pieces are played by an expert musician with expressive final *ritardandi*, recorded as MIDI files. The corresponding MIDI scores are synthesized using the same instrument voicing and set to the same initial tempo. At the same beat position as in the human performance, the final *ritard* is synthesized according to the averaged tempo curve generated from collected kinematic data, normalized to the tempo of the piece at the start of the modulation. A listening test is then performed to determine what, if any, perceptual difference exists between the expert musician performances and the synthesized counterparts.

4. Discussion

After initial testing, preliminary results concur with the notion that there is a connection between locomotion and musical timing. However, much more extensive testing needs to be done to arrive at a concrete conclusion. Interestingly enough, all but one direct comparison of human and machine performance fell within a vote of 50% with no distinct lean toward accuracy or confusion. The one instance in which all listening test subjects correctly identified the human performer, it was observed that slight errors in the performance accuracy were likely perceived as an element of humanity. It should be noted in a test of this kind, artificial intelligence systems have, in the past, passed the Turing test by accurately modeling human error.

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.

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