Notation for Motion Tracking Controllers: A Gametrak Case Study

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ABSTRACT
Notation systems are used in almost all fields, especially for the communication and expression of ideas. This paper proposes and discusses a notation system for Gametrak-based computer music instruments. The notation system's design is informed both by Western music notation and dance notation, as well as common mappings used in laptop orchestras. It is designed to be sound-agnostic, primarily instructing the performer in their motions. While the discussion of such a notation system may be particularly timely due to the growing commercially-available 3D motion tracking controllers, the notation system may prove especially useful in the context of Gametrak and laptop orchestra, for which score-based representation can help clarify performer interaction and serve as a teaching tool in documenting prior work.

Author Keywords
Notation, composition, laptop orchestra, gesture, performance, Gametrak, instruments and electronics

ACM Classification
H.1.2 [Information Systems] User/Machine Systems – Human information processing, J.5 [Computer Applications] Performing arts (e.g., dance, music).

1. INTRODUCTION
Music notations archive the temporal sequence of pieces, and allow their subsequent revivification by musicians. Western music notation, as well as many 20th century graphic notations [9], are based on a desired sonic output, allowing performers to interpret the notation within the context of their instrument, the mappings and control of which they are already highly familiar. However, for a computer music controller, where the breadth of possibility for mappings is large, and mappings are often piece-dependent, it is the motions that the performer must make (perhaps without initial knowledge of the resulting sonic output) that is consistent between pieces. Thus, a notation system centered on performer motion, rather than desired sonic output, allows for a player of that controller to approach different pieces with the same notation in mind. This approach essentially notates the first layer of correspondences that depend only on the choice of the input device for a given set of abstract parameters. This first layer then represents pathways to secondary mappings that correspond to a particular sonic output.

Naturally, gestural notation systems will vary by the given capabilities and degrees of freedom of a controller. Considering the rise of commercially available 3D motion tracking controllers (e.g. Leap Motion, Sixense), a notation system incorporating 3D motion tracking may be useful for interaction designers and composers. While many of these systems involve skeletal tracking of the hand, and thus involve a number of degrees of freedom, all involve locating the hands in 3D space. Thus, a logical controller to investigate for motion tracking notation is the Gametrak. It's intended purpose, and frequent use in the computer music community, is for 3D motion tracking of hand location – it only otherwise consists of a footswitch. Investigating notation for Gametrak has another purpose: to facilitate documentation and sharing of Gametrak-based compositions for the current computer music community. In this paper, we propose a notation system for the Gametrak for this dual purpose of exploring how 3D gestures can be represented in the form of a score, and for providing a notation system for the Gametrak controller for imminent use.

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2. GAMETRAK
For approximately ten years, the Gametrak has proved a flexible choice of motion tracking controller for digital musical instruments (DMIs) [3]. Originally intended for use in home video game platforms or personal computers, the controller features two retractable tether reels, each approximately 13.5 feet in length, set in the main body of the Gametrak via ball joint and guide arm (Figure 1). Two potentiometers measure the *x* and *y* position of the balls (and thus the guide arm), and the *z* position is calculated by two more potentiometers turning inside of a retractable, spring-loaded drum, wherein the number of turns each potentiometer is counted as a nylon tether is pulled [8]. This effectively provides 6 degrees of freedom for continuous position mapping, plus a footswitch for discrete motions.

The Gametrak persists in its use in the computer music community. In ICMC 2015, two performances used Gametraks: *CDM (Convulse, Die, Mourn)* (Jon Bellona, 2015), and *Latency in the System* (Ryan Carter, 2013). *Lariat Rituals* by Jeffrey Stolet (2012) uses solely the Gametrak, and particularly, laptop orchestras, including the Dublin Laptop Orchestra, H-CLEf (Holy Cross Laptop Ensemble), PLOrk, SLOrk, Sideband, and SideLobe (Princeton's and Stanford's laptop chamber ensembles, respectively) use the Gametrak in performances. Since SLOrk's inception in 2008 until 2015, at least 30 pieces out of 102 composed by ensemble members and directors involve at least

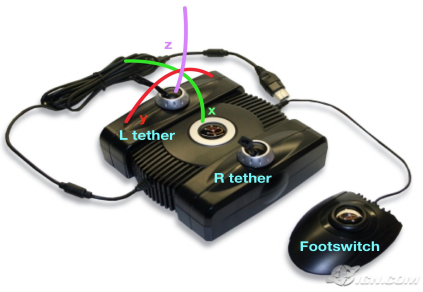

Figure 1: Gametrak controller

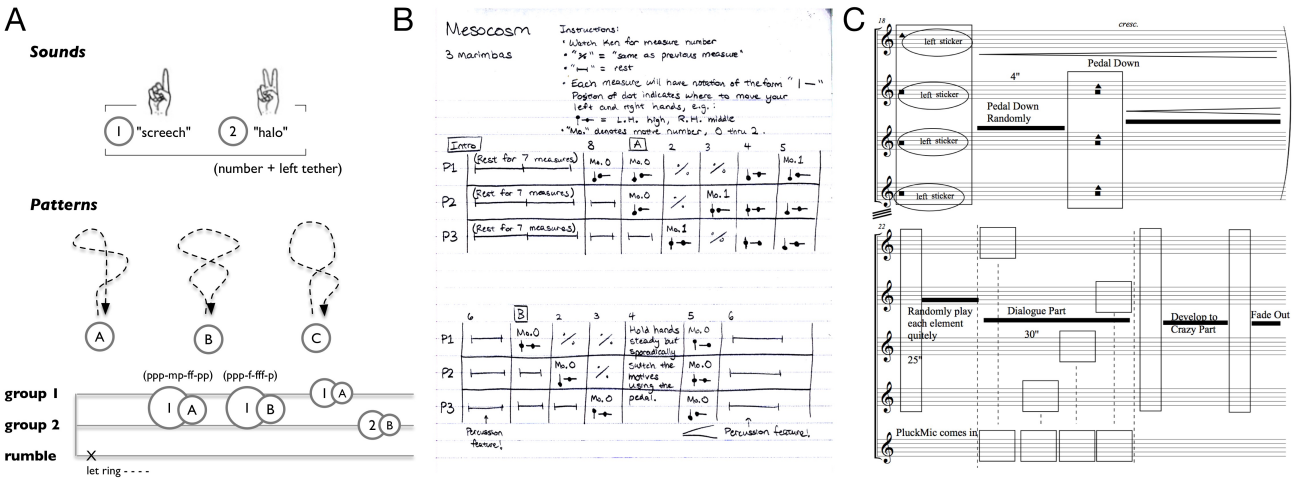

Figure 2: Excerpts of scores for recent Gametrak pieces: A) *Twilight* by Ge Wang, B) *Mesocosm* by Kenneth Qin and Trijeet Mukhopadyay, and C) *Astroballad* by Song Wang

one Gametrak, and in PLOrk in spring of 2015, four out of seven developed pieces involved Gametraks [5], in addition to one presented at NIME 2015 [8].

These pieces however, particularly the ones for laptop orchestra, seem to be infrequently scored – 5 of the 30 SLOrk pieces we knew to use Gamterak had documented scores. We feel that with the addition of a score, Gametrak works may benefit in several ways. First of all, a score makes the relationships of the musical events, represented by the gestures, more apparent and gives the opportunity to the composer to both visualize the material and facilitate editing processes. Second, the addition of the score may help increase performer engagement and reward, as it provides clarity of purpose, helps increase synchronization between players, and provides bounds within which a performer could express him or herself. This would be particularly true as the piece and its mappings for the Gametrak become more familiar [5]. Third, such scores could provide for sharing between laptop ensembles, which has been noted to be infrequently done, despite an increasing number of ensembles [6].

There exist several recent pieces for Gametrak in which the complexity of the laptop orchestra piece required a score (see Figure 2). It is evident that these scores vary in notation strategy, with one containing measures to show the beat-based temporal progression (Figure 2B), and one specifying conductor cues which performers should rely on (Figure 2A). Notably, the clarity of scoring in *Astroballad* (Figure 2C) by Song Wang resulted in a subsequent performance without the original performer and composer. Each of these composers tackled creating a score architecture for Gametrak and communicating it to performers. A unified notation that is both flexible in its structure to accommodate the variety of structures of pieces may not only prove useful in future pieces for the reasons stated above, but may also further save time for composers by providing the basis of a notation system to use.

3. NOTATION SYSTEMS FOR MOTION

When considering notation systems for human movement, it is logical to look to dance notation systems. Systems of dance notation have been developed for centuries to document dance choreographies, with early systems primarily documenting foot patterns. As choreographies became more complex in the 20th-century, notation systems based on abstract symbols developed, notably those of the Margaret Morris, and Rudolf von Laban [4]. The system of von Laban, called Labanotation, consists of abstract symbols for direction, length of time, and level of a movement for several body parts. Notably, it does not make reference to codified dance steps or style characterizations; movement is always considered in spatial terms like up, down, to the side, backwards, etc. In this way, it is considered to be quite flexible to different dance styles, and along with film, it is today the most widely used method of documenting dances.

The NIME community has also recently developed gesture-based notation systems. In NIME 2015, a notation system for multi-touch interfaces was proposed and tested, using a series of symbols to indicate types of interactions with the interface, including short taps, finger drags, and a sequential series of touches [2]. A notation system for the Karlax Controller was presented in NIME 2014, closely addressing the motions the performer should make for this particular controller [7]. For example, the 10 keys of the controller were represented on a grand staff where one line represented the button for each finger, and the orientation of the controller was represented through a series of concentric circles with the direction of the controller represented "like the hands of a clock". Aspects of both of these systems have been adopted in the present notation; however, the present system focuses wholly on 3D gesture representation.

4. PROPOSED NOTATION SYSTEM

We have developed a flexible, general-purpose notation system for Gametrak-based DMIs. The notation system has been informed by many sources, including frequent uses for Gametrak instruments (particularly those created during the past six years of the Stanford Laptop Orchestra), scores developed for Gametrak instruments, and dance notation, as well as the authors musical sensibilities. At its core, since the Gametrak encourages full involvement of the arms and/or torso by continuous motion associated with the tether (and discrete motions associated with the foot pedal), our notation system takes the physical motion required of the performer as its main symbols. Note we will be not addressing the mapping strategies to sound synthesis.

4.1 Tethers

We strongly represent performer's motion of the Gametrak tethers in the notation system. Inspired by dance notation where motion and form are simultaneously represented, we adopted a similar symbolic procedure.

For pieces in which both tethers are frequently used, the two tethers can be represented on individual staves, with the top portion of each staff representing a 2D birds eye view of the *xy* axes of a tether, and the bottom portion representing a frontal view of the *z* axis (Figure 3). Note that, if a piece trades off between tethers, only using one at a time, the 'R' and 'L' can be noted on one staff, with the letters 'R' and 'L' indicating which hand should be presently used, similarly to how you might notate a change in clef in Western notation.

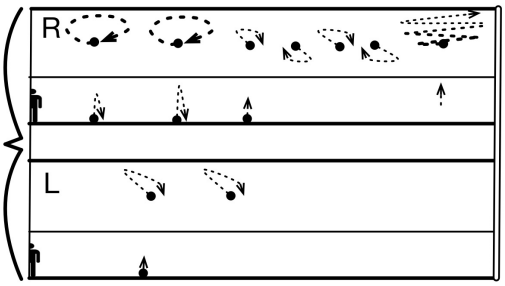

Figure 3: Tether Motion Representation

4.1.1 Spatial Location

The point where each tether is set into the body of the instrument is represented by a black filled circle, providing a stable point of reference to which the performer's actions are relative. The magnitude of the *xy* gestures is spatially represented relative to one another: a small deviation away from the center point represents a small spatial movement, and likewise for large movements. A dotted line and arrowhead represent the spatial trajectory that a performer should take, similarly as in the *Twilight* score (Figure 2A). In order to specify exactly at what height the gestures should be made, a character icon of a person is given at the start of the *z* axis, to which the motions on the staff should be made relative. This also allows a composer to specify the range of the intended motions as well as the placement of the Gametrak. If a full person is present, the Gametrak should be placed on the ground. If the torso and above is shown, it is expected that the Gametrak should be placed around hip height (i.e. either on a table, or on the ground with the performer kneeling). To avoid redundancy, height of the action should be performed at the last specified height unless otherwise marked.

The top and bottom of each staff are meant to be read concurrently, so that a gesture is represented in 3D. In this way, the notation encourages a performer to think gesturally, mentally rehearsing sounds as shapes. We opted for this two-tiered staff representation over 3D coordinates for clarity of movements, as well as ease of drawing.

4.1.2 Velocity

The velocity of a motion is represented by the thickness of the line, with thinner representing a slower motion, and thicker representing a faster motion.

4.2 Footswitch

The press of the footswitch is notated at the base of the top staff, by a dark square, with rightwards extensions of the box in the case where the pedal should be held for extended periods (Figure 4).

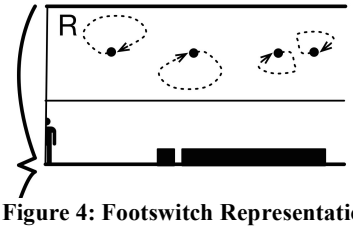

Figure 4: Footswitch Representation

4.3 Time

In this notation system, time flows from left to right, but how strictly in time it should progress depends on the composition. If it is a strongly timed piece with a metric structure, blocks might represent regular units of time in which the notated gestures are to fit, i.e. relative to a beat (Figure 5A). However, for rhythmically unstructured music, approximate time markers may represent the flow of time (Figure 5B). For this latter case, synchronicity between players can be indicated by a bounding box around the synchronized parts in a score. This indicates to the players that it is important to either make a certain gesture or set of gestures at the exact same time, or in the exact sequence relative to each other as printed on the page. This was inspired by the *Astroballad* score, for which joint actions felt very clear to the players.

To eliminate redundancies, repetitive motions can be indicated by an ellipsis until the next temporally specific instruction, or by a specific frequency of times the motion should be made (e.g. 5x).

4.3.1 Interaction with Velocity

Since velocity is represented by line thickness, two gestures that take up the same amount of space on the staff may take different amounts of time. As a result, even on the gesture-to-gesture timescale, time may not be represented linearly on the page. We feel that, while linear time representation makes for an intuitive reading of a score, since many pieces involving Gametrak are not metered and are meant to be somewhat free in time, accurate spatial and velocity representation was a reasonable trade off for a non-linear time representation.

4.4 Dynamics

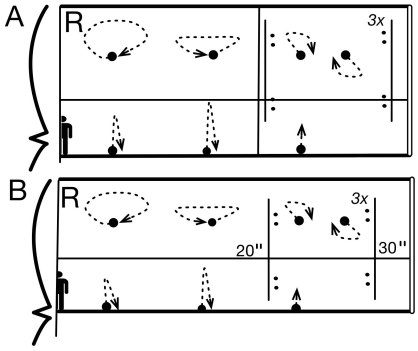

Figure 5: Temporal representation
A) Measured B) Unmeasured

It has been noted that the most common mapping of *y*-axis in 2D joysticks is amplitude control [1]. Similarly, we found in our review of Gametrak instruments in SLOrk that a common mapping for the *z*-axis is gain control. If an instrument's *z*-axis is solely mapped to gain, we propose removing the bottom portion of each staff and instead, adding a layer of Western dynamics (Figure 6). This will help to free the page from one more (otherwise necessary) layer of notation, and should be an intuitive and easy adjustment for a performer to make, especially one who is comfortable with our original notation.

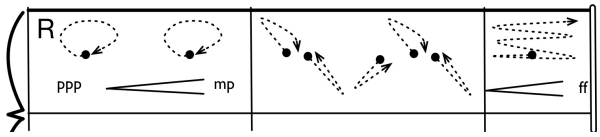

Figure 6: Optional dynamics representation for when z-axis is mapped to dynamics.

5. DISCUSSION AND EVALUATION

In our research of Gametrak-based pieces, we have observed a wide range of styles of interaction, compositional structure, and notation. Some notations pair simple actions description with sound manipulation. For instance, in Ryan Carter's *System,* the general motions for each tether, such as 'pull', 'sideL', 'frontR', are the only instructions. Others lack notation systems, but have complex instruments which include specific event triggers at precise locations in 3D space (frequently seen on the y axis, as in *41 Tentacles* (Trijeet Mukhopadyay, TJ Melanson, and Dan Spaeth), *Fuyuen* (Romain Michon), *Ennui* (Trisha Shetty, Nathaniel Shak, Janna Huang)), with gain control on the *z* axis and pitch on the *x* axis, and some using the footswitch, as in an arrangement of *In C* (Terry Riley, arranged by Madeline Huberth, Rob Hamilton, Ge Wang) for which the footswitch triggers the start of the next melodic figure.

The notation system is designed to be flexible in allowing for a similar representation of the aforementioned pieces, and is thus more similar to tablature or dance notation than to traditional music notation – it notates gestures, rather than sonic outcomes. We acknowledge that this focus on gesture may perhaps result, at least initially, in only a one-to-one mapping mindset of the performer, because when reading a score, a performer may initially think only about the one motion they must make, rather than the potentially more complex sonic outcome, especially if the instrument takes a one-to-many mapping strategy.

However, the simple representation of otherwise complex sounds may provide a straightforward path for performers, which would be ideal for beginner players or those new to a particular mapping [10]. It is hoped that, in combination of familiarity of an instrument, the performer will internalize both the gestures and the resulting sounds, and encourage exploration of closely-related expressive paths to what exists in the score, essentially allowing for performer interpretation of a work. This move from action-based motion to eventual symbolic representation seems a logical progression in learning an instrument or piece. If a representation of the sound is highly desired by the composer though, he or she can easily add an extra layer to the score.

6. INITIAL EVALUATION

Aspects of the system were refined with some user feedback. Volunteers (two members of SLOrk 2016 and a previous SLOrk director) informally evaluated the system by playing an example score after a brief introduction of the basics of the notation. Their speed of learning and areas of confusion were noted, and they each gave comments on how the notation could be improved, which were incorporated into the system put forward in this paper. Particularly, an earlier version of the notation system had two heights at which a foot pedal could be marked – one signifying a simple press, and one indicating a press meant to be held from some length of time – which one user commented was redundant. Regarding ease of reading the notation, the tiered staff in which the top portion shows a birds-eye view and the lower a height-based view seemed to pose no difficulty to the users. There was some initial confusion about whether to use one or both hands for any notated motion. This may have been due to the specific method of scoring chosen, in which right and left tethers were collapsed into one staff (as proposed at the end of section 4.1), and motion for either hand was indicated by an "R" or "L". However, after the notation was clarified to them, they quickly adjusted and were able to distinguish between hands more easily. While there was some initial confusion, this method of collapsing the hands into one staff saves space on the page and allows the eye to follow the music more linearly. However, an interesting comparison would be to present users with two versions of the score: one in which the notation for each hand is presented on the same staff, and one in which each hand has its own staff. While the latter may result in a sparser page (piece-dependent), it may aid in clarity of left/right hand movement in unfamiliar scores.

Naturally, working with composers interested in scoring their Gametrak-based piece, and feedback from performers of a complete piece will be an invaluable test of the notation. We are currently working with one present SLOrk composer on a piece to be performed in 2016, and hope to present our observations and the notation's resulting refinements in future work.

7. CONCLUDING REMARKS

In this paper, we have described a notation system intended to specify the motions that performers should make in a Gametrak-based piece, which may aid in the compositional process, performer synchronization and expression, and piece documentation.

We aimed to provide a sound-agnostic notation – by focusing on the motions required of a performer, the notation system is flexible in its application to different mappings, providing a baseline system for composer and performer use. Naturally, Gametrak-based pieces come in many varieties, including those which are intended to be primarily improvised, in which case, notation may prove less appropriate. Regardless, we hope this notation system will be useful in documenting and disseminating Gametrak-based compositions, as well as increasing performer engagement with a piece.

Such a system of notation based mainly on motion representation in space may also potentially link compositions for 3D environments and multi-axis controllers such as the Leap motion, and the Oculus touch. While in a CAVE or 3D panel displays our notation system will work well, other issues might arise when a head-mounted display (HMD) is worn. The notation must either be learned outside of the HMD, or must be rendered within the HMD, perhaps to be removed once the user becomes more familiar with the mappings and the resulting sounds. Hopefully the issues and decisions made in the present notation systems' design will further discussion on what notation systems may look like for more complex controllers.

The notation presented in this paper can be made in many graphical editors, and a template for one choice (OmniGraffle), as well as several re-scored pieces using the proposed notation system are available at slork.stanford.edu/works/.

8. ACKNOWLEDGMENTS

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