

Mapping and dimensionality of a cloth-based sound instrument

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Abstract—This paper presents a methodology for data extraction and sound production derived from cloth that prompts “improvised play” rather than rigid interaction metaphors based on preexisting cognitive models. The research described in this paper is a part of a larger effort to uncover the possibilities of using sound to prompt emergent play behavior with pliable materials. This particular account documents the interactivation of a stretched elastic cloth with an integrated sensor array called the “Blanket”.

I. INTRODUCTION

Interaction can be characterized in several different ways. Structural models of gesture have informed efforts to design interactive sound systems, particularly for music performance [2]. Principles derived from human-computer interaction and music cognition studies considering task complexity [16], cognitive load [9], and engineering considerations [12] are common bases for design. At the level of design theory, a conceptual framework for digital musical instrument design proposed by two of the authors applies human-machine interaction and semiotics to musical performance [10].

At the same time, theories of embodiment suggest modes of interaction behavior may emerge outside the cognitive or linguistic realms. The design of a gestural interface with sound feedback need not rely on semiotics or an assumption of an agent actor. Avoiding such assumptions eliminates a reliance on intentionality for control, and allows the possibility of emergent play behaviours [17].

Incorporating aspects of both of these paradigms, this project is part of *Wearable Sounds Gestural Instruments (WYSIWYG)*, a research effort aiming to create a suite of soft, cloth-based controllers that transform freehand gestures into sounds. These sound instruments [18] [6] can be embedded into furnishings or rooms, or used as props in improvised play. Sound should respond to diverse parameters such as proximity, movement, and history of activity. The interactions are designed in the spirit of games like hide-and-seek, blind-man’s buff, and simon-says, which work well with a variable number of players in live, ad hoc, co-present events. The goal of this particular “wysiwyg” was to present a simple fabric-based interface that can be used to explore synthesis methods that best represent interactions with cloth.

Fusing fabric art with digital feedback systems holds promise because the interaction characteristics of fabric are well known. Fabric is malleable, tangible, textural,

and material. It promotes multisensory, haptic modes of exploration and manipulation. It carries a pre-existing context of gesture and expression that need not rely on linguistic tokens to represent interaction modes; instead, the surface dynamics of cloth generate recognizable states based on structural similarities. For example, a “fold” is recognizable even though the set of all possible transformations that could be called a fold is infinite. Characteristics such as these are independent of their specific physical manifestation in cloth.

Textile environments have been widely used in art and sound installations. [11] and [14] embedded electronics into articles of clothing as a platform for interactive performance. Textiles themselves have been used as a physical interface in [18] and [13]. Fabric-based installations on an architectural scale include [3] and [15]. A detailed physical model of textile properties has been developed by [4] for musical control; however the user interface was graphical rather than physical.

II. THE SYSTEM

To explore these concepts, a physical interface was constructed. The **Blanket** is a 3x3 meter square piece of elastic fabric. Sewn into its top surface is a sensor system is made up of 25 light-dependent resistors (LDRs) arranged in a 5x5 array. The control surface of the interface consists of the entirety of the cloth. In exhibition, the fabric is stretched by its corners and elevated about 1.5 meters off the ground. It may be touched, stretched, pushed up, pulled down, shaken, scrunched, or interacted with in any way the human body might be applied. It is large enough for several people to interact with it simultaneously.

The LDRs become “motion” sensors with the use of theatrical lighting. Beams of light are strategically positioned perpendicular to the Blanket’s top surface so that when it is put into motion, the amount of light received by the sensors varies as they are brought nearer and further from the center of the beam. The voltage output of the sensor system is sampled by an Arduino A/D converter [1]. Preprocessing, mapping, and synthesis take place in Max/MSP.

III. GESTURE TRACKING

Gesture has been defined as an intentionally expressive bodily motion recognized in a particular cultural context [8]. However the Blanket system does not acquire the



(a) The interface at rest



(b) Interaction

Fig. 1. The Blanket

gestures of the humans. Rather it maps cloth behaviors to sound parameters that promote precognitive interaction. In this sense we are tracking the “gesture” of the Blanket rather than that of the human interactors, using the word gesture to refer to a single contour within the sensor system’s total response, arising through the application of some data extraction method. Because intentionality is purposefully omitted, “noise” is also defined by the data analysis approach, and consists of all of the confounding factors when attempting to isolate a specific cloth behavior. Differentiating signal from noise thus necessitates a specification of what constitutes a unitary contour in the data stream. A cloth gesture could be said to be the aggregate of the intentional and unintentional gestures of the interactors, the physical properties of the cloth, and the contextual environment of the performance.

Because the goal of this research is to determine how to generate meaningful sound derived from the “raw” physicality of cloth, feature extraction for this interface was limited to three functions: total activity (the values of all sensors are added, reflecting the total kinetic activity of the interface), sensor velocity, and activity “spike” (a sudden change in value that exceeds a preset threshold). Each of these functions make available a dynamic data stream for mapping to audio parameters.

The sensor system is by its nature a 2-dimensional array that moves in 3-dimensional space, which prompts the question of how to sample the array. A sampling technique consists of a spatiotemporal sequencing of individual sensor outputs defining a unique “domain”. Domains are orderings of the sensor array that include all discrete sensing points once and only once, but may segment sensor readings into groups. These constraints are inspired by measurement theory, in the hopes of obtaining a holistic “snapshot” of the state of the entire interface.¹ Depending upon how the array is sampled, contours in

¹To test for dimensionality of a set of points N , the points inside a given radius N_r may be counted. Because the 2-dimensional sensors array may be approximated as a “point cloud”, using all points once and only once within r^2 will best represent its dimensionality.

the signal correlating to gesture are mapped to sound synthesis parameters. Three strategies were employed for sampling the 2-dimensional array: *string*, *sectors*, and *atoms*. Each method offers its own distinct approximation of the gestures traveling through the cloth.

A. String

The string model treats the data points as a space-filling curve. In this schema, the 2-dimensional array is linearized by scanning all sensor values via a “walk” along the surface of the fabric, consolidating the total output of the sensor array to drive a single synthesis parameter. The domain’s differentiating characteristic is that it is a 1-dimensional ordering of the set.

The path of the scanning sequence can be arbitrary, but physical properties of the cloth at each point on its surface have a profound effect on the string. For example, because the corners of the cloth are immobilized by supports, there is a damping effect which is most pronounced at the Blanket’s corners and edges, causing an increase in the relative kinetic motion of the Blanket’s center. When the interface is used as a vibrating membrane, modal physics affects sensor outputs. Two scanning paths were utilized to observe how physical factors influence the perceived meaning of the sound output: a spiral and a switchback.

The spiral walk begins at one of the outer corners of the interface, where motion is dampened by the support ropes, and spirals inward to the Blanket’s center. For the first mode, the points with the lowest kinetic energy are concentrated at the beginning of the walk and those with the highest are at the end. The switchback gives this damping effect a period, as peripheral points are equally distributed among internal points. Arbitrarily chosen walks will, of course, always be subject to the effect of damping, light source placement, and human factors arising from the embodiment of interaction behaviors. Because the string domain was used to map each sensor value to a virtual mass on a string for scanned synthesis using the *scansynth*~ object [5], the effects of any walk are evident in the timbre of the resulting sound. Out of

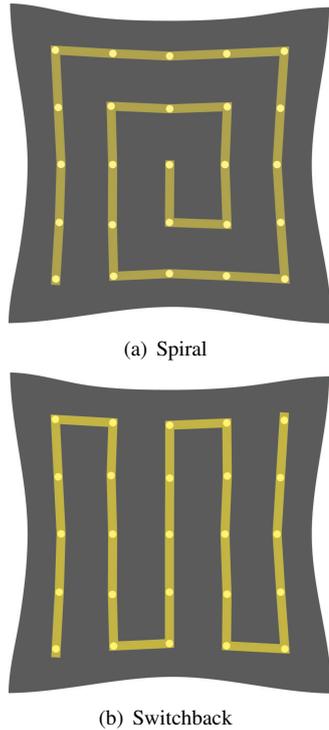


Fig. 2. Two possible paths for defining a “string” domain

the three domains, the string model is most responsive to the kinetic properties of the entire interface.

B. Sectors

The sector model has two primary aspects, namely a dividing of the cloth into sonically-autonomous regions, and data smoothing within those regions by averaging all the points within them.

The patch uses the *matrixctl* object to allow the sound programmer to select multiple contiguous regions of the Blanket and differentiate them as sectors. A mapping can then be implemented between the data associated with each sector and the sound parameters of a corresponding instrument. Although no ordering information is preserved by the translation from the domain of sensor grid to that of sectors, the membership clause of contiguity assures a relationship between the sectorized data points in two-dimensional space. Since sectorization downsamples the two-dimensional array to extract data values by area, the illusion of a unified response taking place over the entirety of each sector is created. As a result, gestures over the control surface take the form of an interaction between such distinct forces. Using each sector to control a separate instrument creates a polyphonic effect.

The sector approach is not without its weaknesses. Averaging several points risks including sensor data that is either redundant or not engaged in the interaction, as do the constraints imposed by contiguity and the inclusion of each data point exactly once. Additionally, sampling fewer than all sensors may give an equivalent result, and the activity of non-contiguous regions may be accurately represented by one voice due to modal properties of the

Blanket. However these weaknesses are accepted as the price paid for choosing to preserve a holistic view of the surface.

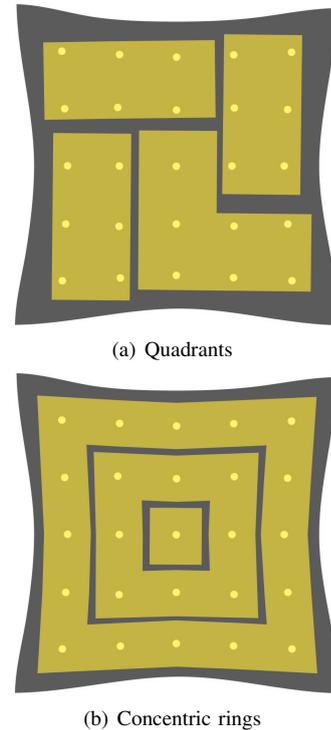


Fig. 3. Two “sector” domains

Some possible choices for sector boundary conditions include sectorization by geometry or by physical property such as damping conditions, proximity to light source or performance-specific contingencies. Each choice implies an assumption about what data should be considered a unified force and so responds according to a different model of meaningful interaction. For example, sectorization by quadrant assumes that the most meaningful distinction between forces is absolute location of an interactor, whereas a partition by concentric region or by damping conditions emphasizes the physics of the control surface. For the final sector implementation, the decision was made to group sensor data together by quadrant after observing the temporal scale at which a gesture would resolve over the entirety of the Blanket. Two results of this decision are that participants concentrated in a quadrant of the Blanket are encouraged by the sonic feedback to cooperate, and participants located separate regions of the Blanket have primary influence over the voice(s) associated with their sector.

The quadrants were sonified by mixing four granular synthesizers. The intensity of each voice was controlled by the overall amount of activity in the associated quadrant, while textural properties such as amount of grains and pitch were controlled by rate of change parameters.

C. Atoms

Mapping each data point individually to its own sound source preserves the entirety of the interface’s output

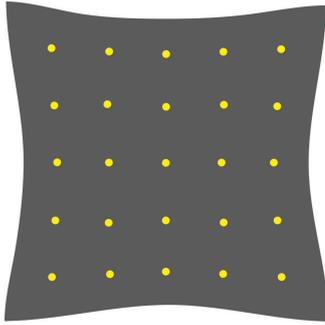


Fig. 4. Atoms

without adding any assumptions about ordering or location. By treating each sensor as an “atom”, it is given a unique voice independent of the state of the entire Blanket. However, because the sound synthesizer responds to each atom simultaneously, the sound is still tightly coupled to interaction gesture, which is expressed as temporal variation of the atoms. A relationship between points is manifest in the response of the sound instrument, but is not inherent in the definition of the domain. Without any ordering or grouping information whatsoever, this domain could be said to have zero dimensions; it makes no assertions about the dimensionality of the ambient object. Because assumptions about dimensionality are minimized, this approach may be said to avoid corruption of the data as a result of mapping choices. Gesture is discernible in the sound, but not in the data.

The synthesis implementation consists of a wavetable “scrubbing” technique. Each atom controls the position of the playback head in its own *waveform~* object. Velocity is mapped to the scrubbing speed and direction, so that kinetic energy and direction of motion are represented by pitch and timbre, respectively. A smoothing function has also been applied to act as a threshold, so that minute changes in sensor outputs when the interface is at rest do not cause low frequency noise.

IV. DISCUSSION

If the strict adherence to domains are relaxed, many possibilities emerge. Defining subsets of domains as non-contiguous groupings of points allows greater freedom to account for redundant or unnecessary information. Periodic motion or absolute position may in fact be detectable without all of the sensor data.

The three dimension-based mapping strategies outlined above are similar in that they are ways of viewing the gesture of a whole object. In practice sound instruments can adopt each paradigm in succession or can incorporate all three into their data extraction process. The three approaches may be used together in the same performance — either in parallel to control different aspects of the sound feedback, or in sequence to delineate game stages. Used in parallel, the domains could control multiple timbral features of the same sound instrument. In sequence, the shift from one domain to another could symbolize

a state change arising either from interaction events or compositional choices. Further, the audio output can be produced by many sound instruments, each enforcing a separate abstraction on the same data stream. Thus the appropriateness of a given domain is based on the sonic result of perceived gestures, the ability of sonic feedback to direct gesture or to influence play behavior, compositional factors, and human and environmental behavior.

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