The Fragment String

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ABSTRACT

The Fragment String is a new digital musical instrument designed to reinterpret and reflect upon the sounds of the instruments it is performed in collaboration with. At its core, it samples an input audio signal and allows the performer to replay these samples through a granular resynthesizer. Normally the Fragment String samples an acoustic instrument that accompanies it, but in the absence of this input it will amplify the ambient environment and electronic noise of the input audio path to audible levels and sample these. This ability to leverage both structural, tonal sound and unstructured noise provide the instrument with multiple dimensions of musical expressivity. The relative magnitude of the physical gestures required to manipulate the instrument and control the sound also engage an audience in its performance. This straightforward yet expressive design has lent the Fragment String to a variety of performance techniques and settings. These are explored through case studies in a five year history of Fragment String-based compositions and performances, illustrating the strengths and limitations of these interactions and their sonic output.

Author Keywords

digital musical instruments, granular synthesis, game controllers, human-computer interaction

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.2 [Information Interfaces and Presentation] User Interfaces—Input devices and strategies, H.5.3 [Information Interfaces and Presentation] Group and Organization Interfaces—Collaborative computing.

1. INTRODUCTION

The Fragment String (Figure 1) is a new digital musical instrument designed to reinterpret and reflect upon the sounds of the instruments it is performed in collaboration with. To that end, its core is a granular resynthesis engine applied to sampled live acoustic input. The parameters of the granular resynthesis are controlled by two strings that are pulled from the body of the instrument and moved about in space. In our experience of performing with the instrument, the resulting interaction is accessible, nuanced, and engaging of the body, easily understood by beginning performers, while enabling subtle layers of musical expression for seasoned practitioners. The relative magnitude of the physical gestures required to manipulate the strings and control the sound also engage the audience in its performance.

The Fragment String raises interesting questions related to performative aesthetics of digital music instruments. As it is fundamentally a sampling instrument, Fragment String requires additional instrumentation or sound generation mechanisms for it to operate in a musical setting. Given a complementary sound source to work with, it is then able to achieve its own sonic identity derived from its input; without this, it fails to achieve reasonable criteria for an expressive musical instrument.

However, the Fragment String was designed with one additional source of input sound: the background noise of its environment and its own electronic circuits. Using a dynamics processor, the Fragment String amplifies these to readily audible levels when no instrumental input is detected, sampling them for granular playback. While these sonic materials are generally insufficient to produce an adequate musical performance on their own, they do afford the instrument a distinctive, whispery "voice" that provides contrast with instrumental sonic materials.

Together these characteristics have produced an instrument that is straightforward to learn but offers depth in multiple dimensions of musical expressivity. As such, the instrument has been used in seven individual musical works spanning the past five years, developing a small but meaningful repertoire. Each of these compositions has explored different facets of the instrument's sound-producing capabilities and interactions. These musical works have also placed the Fragment String in a number of roles: that of an ensemble instrument, that of a single Fragment String performer with accompaniment, and that of a performer

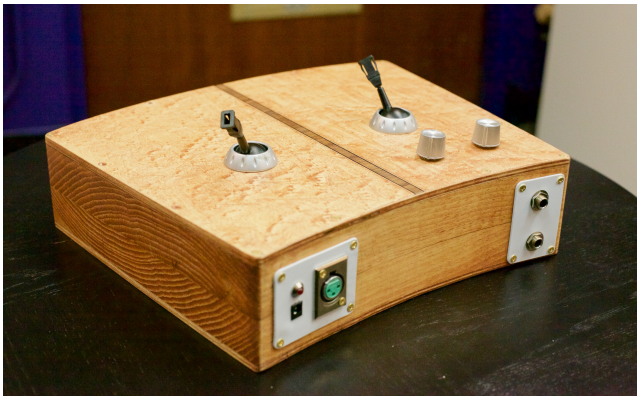

Figure 1: The Fragment String.

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playing an acoustic instrument and Fragment String simultaneously. Through these compositional and performative experiences, many of the merits and drawbacks of the Fragment String's design have been made evident.

2. BACKGROUND

The aesthetics and philosophy of instrument building underlying Fragment String are rooted in the principles advocated by and practiced by Dan Trueman, Perry Cook, and Curtis Bahn. Trueman's BoSSA [14] augmented a spherical array of speakers with sensors mapped to musical synthesis, fusing into a single object its gestural inputs and its means of acoustic sound projection. As a digital music instrument, the BoSSA heralded a return to a more classical acoustic instrument paradigm, in which sound directly emanates from the instrument being performed itself. These ideas were further explored in the musical duo "interface," a collaboration between Trueman and Bahn, the former of whom performed with BoSSA and the latter of whom projected the sound of an extensively customized electric bass through a number of spherical and hemispherical speakers in close proximity [1]. Trueman considers the concepts underlying these efforts and similar work with the Princeton Laptop Orchestra [11] using two criteria, *sonic presence* and *performative attention* [12]. Sonic presence concerns itself with how the sound of an instrument is contextualized acoustically with a greater electroacoustic ensemble. Performative attention considers how much effort and attention a digital music instrument asks of its performer, how hard or easy is it to play, and if it can enable the development of "virtuousity." Ruviaro's definition of a musical instrument complements these considerations, considering presence, movement and gesture, and historical context as the defining qualities of a musical instrument, digital or otherwise [10].

The systems described above were necessarily tethered to external computers to perform the relatively heavy processing tasks associated with analyzing sensory input and synthesizing the resulting audio. More recently, technological developments such as the BeagleBoard, Raspberry Pi, and other single-board computers have allowed the body of a digital musical instruments to physically encompass the entirety of gestural input, acoustic output, and the computational activities associating the two, obviating the need for a thicket of cables running back to a "real" computer. The advantages of these systems for digital musical instrument design have been discussed by Berdahl and Ju [2, 3] and Moro et al. [7].

The development of Fragment String was directly inspired by the trend of appropriating game controllers as the basis for digital musical instrument designs. In particular, a performance of Anne Hege's *From the Waters* (2012), by the Princeton Laptop Orchestra, inspired explorations into the use of the Gametrak golf gaming controller towards musical ends. In *From the Waters*, the ensemble members pulled at and shifted around a single loop of rope tethered to multiple of these controllers in a ritual-like performance. While many computer music works, intentionally or not, draw attention to the technology underlying them, *From the Waters* seemed to use its technical implements to in fact conceal the role of technology in its production, placing in the foreground the activities of the performers and the musical results thereof. This quality can be partially attributed to the work's creative use of the Gametrak controller, which remains obscure in the field of computer gaming interfaces but nonetheless provides interesting and unique gestural opportunities for digital musical instrument designers. These manifold possibilities have been explored and documented extensively by Freed et al. [4], Trueman [13], Rotondo et al. [9], Huberth and Nanou [6], and Jinshuo Feng in his *Line of voice and string* (2016).

The practice of amplifying the acoustic presence of a space with or without instrumental sound present is well-established in the history of 20th century music. Alvin Lucier's *I Am Sitting in a Room* (1967) is perhaps the best known example, in which subsequent recordings of the piece's text are filtered through the titular room, accentuating the its distinctive resonant properties. Gordon Mumma's *Hornpipe* (1967) incorporated two small microphones attached at a solo horn player's hip, distanced from the horn itself; custom electronics would automatically sample and replay the sound of the horn in space. As stated by Mumma, the musical results of this process were highly dependent on the acoustic properties of the space itself [8].

3. MOTIVATION

The Fragment String was borne of several intersecting desires in creating musical instruments for the Stanford Laptop Orchestra [15]. One of these was to study and introspect the sounds of the real world on a small scale, and to incorporate these activities into a musical piece for a computer music ensemble. This was further intended to manipulate live sound in real time, making transparent the nature of the sound processing and enabling a mechanism for dynamic musical interplay between acoustic and digital instrumentation.

Another desire that motivated the Fragment String was to create an instrument that could engage a concert audience more effectively than a wall of laptop screens. As discussed by Henke [5], live computer-generated music, by default, lacks clarity into the actual processes of its performance. Listeners at a computer-generated music concert often have no insight into the techniques being employed by its performers, and perhaps these processes would be overly abstruse or uninteresting to the audience in any case. While computer technology has allowed entire virtual symphonies to be called up with little or no exertion on the part of a performer, the elusive link between physical presence, gestural action, and musical output has arguably persisted in computer music performance.

As touched on by Trueman [12] and Smallwood [11], creating an instrument for laptop orchestra often involves creating an entirely new interface for musical expression, composing a work for that new instrument, and teaching its mechanics to a group of performers. Composers of works for laptop orchestra do not have the luxury of performers who have dedicated multiple decades to their chosen instrument; in the experience of one of the authors, often an ensemble will have only practiced with a new digital music instrument for a few weeks before taking to the stage. Therefore the basic functionality of a digital musical instrument for laptop orchestra must often be easy to understand and generally not require an exceptional number of rehearsals to perform the tasks required by the composition it is intended for. On the other hand, this should not be used as an excuse to make digital music instruments that lack depth, nuance, or expressivity that might only be discovered after some amount of practice. Care is needed to balance a new instrument's required skill and the musical potential of its sonic inventory.

The circumstances of composing for laptop orchestra guided the initial development of the Fragment String, but it soon become evident that the instrument might be used in smaller musical groups (Section 5 discusses these efforts).

4. INSTRUMENT DESIGN

The basic design of Fragment String is two strings drawn from a box that is typically seated on the ground at the feet of the performer. An input source, typically an acoustic instrument sampled through a microphone or pickup, is recorded by the Fragment String continuously. Each string records this input into its own separate buffer of audio. Up to ten seconds of continuous audio is recorded; beyond this, samples will be overwritten starting with the earliest. The instrument effectively samples up to the most recent ten seconds of input.

Drawing a string upwards and pulling it out of the instrument's housing will cause the corresponding buffer to stop recording and enter playback mode. In this mode, the string plays back the current contents of its buffer, at a gain exponentially proportional to the length of string drawn. The buffer does not automatically advance its position in the recorded sound; instead, it freezes the current position in place and replays a cluster of fragments around the playhead. The string can also be moved forward away from the performer or backwards toward the performer to respectively advance or move back the playback buffer position. At all times the performer is in control of the buffer position; the instrument simply plays back a cloud of fragments surrounding the current position. Moving the string left or right adjusts the playback rate of the individual fragments, granting pitch control of the sample.

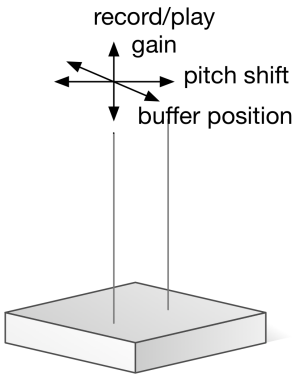

Figure 2: Diagram of operation of a single string.

Returning the string to the fully withdrawn position will stop playback and resume recording for the corresponding buffer. The previous contents of the buffer are entirely cleared and a new buffer of sampled audio up to ten seconds in length is accumulated. The two strings are independent of each other; in addition to recording and playing separate buffers, one can record while the other plays, or vice versa, or both can record or both play, according to the musical intent of the performer and/or composer. As summarized in Figure 2, moving the string up and down activates playback and controls gain, forward and backward controls the current playback position with the sample, and left and right adjusts pitch.

The audio input of the Fragment String is processed with extreme dynamic range compression, such that if no instrumental input has been received recently the low-volume noise of the input signal is amplified to audible levels. This captures both electrical noise from the analog signal path and the ambient sound of the space, captured through the instrument microphone or pickup. If one string is playing while another is recording, and no instrumental input is present, the instrument will effectively sample itself filtered through the reverberant characteristics of the performance space.

This design has led to an instrument fundamentally about exploring and probing the sounds of individual instruments in addition to the intricate and often-ignored sounds of space and electronic noise. Fragment String gives its performer direct control over the recreation of samples of these sounds, with the goal of directing these explorations towards musical ends.

4.1 Performance Techniques

This instrumental design has led to a number of standard techniques for performing with the Fragment String. By advancing the string forward at a suitable rate, the performer is able to play back the sample similar to how it sounded originally. The string can be held in one place to maintain a constant drone, effective when used in tandem with the acoustic instrument playing off of the drone. In this gesture, the string can be slowly raised and lowered to vary the dynamics over time, and can also be pulled out to the left or right to adjust the pitch and register of the drone if that is musically desirable, up to an octave lower or higher than the original sample. As mentioned previously, the ambient environmental sound and line noise of the system can be sampled and replayed at readily audible volumes, creating a texture that contrasts with the tonal, acoustic instrumentation rather than reinforcing it. By alternating the left and right strings between recording and playing, the sampled sound can be "traded" back and forth between the buffers, filtering it each time through the speaker, the acoustic environment of the performance space, and the microphone input. This last technique can be used with either instrumental samples or ambient noise samples.

4.2 Technical Implementation

At the technical core of the Fragment String instrument is a software program that samples from an audio input device and regranularizes the sample in response to user control. This program is implemented in the ChucK audio programming language [16]. The Fragment String software is functionally agnostic to what its actual audio source actually is, be it a built-in laptop microphone, line input, or full outboard audio interface with professional microphone. Various iterations of the Fragment String have employed all of these.

The standard "first-edition" Fragment String consists of a laptop computer running the core software, a Shure SM57 microphone connected to an audio interface providing audio input, and either stereo output to the house sound system or six-channel output to a hemispherical speaker. Variations of this arrangement were used in the bulk of the performances described in Section 5.

More recently, a "second-edition" Fragment String was developed to unite its modular parts both physically and conceptually (Figure 1). For this, an enclosure was developed to house the Gametrak controller, a Raspberry Pi single-board computer to run the software and mediate the various hardware components, a USB audio ADC with built-in microphone preamp, an Arduino to process input and output gain knobs, and an audio daughterboard for stereo audio output. This firstly resolved the practical issue of needing to plug in some form of all of these components when setting up for a performance and needing to disconnect and transport all of these when breaking down afterwards. It secondly resolved the aesthetic issue of the instrument being divided into disparate, loosely connected parts; bringing these together into a single box in a sense "promotes" it from an ad-hoc assembly of hardware and software to a musical instrument that might be reasoned about as such.

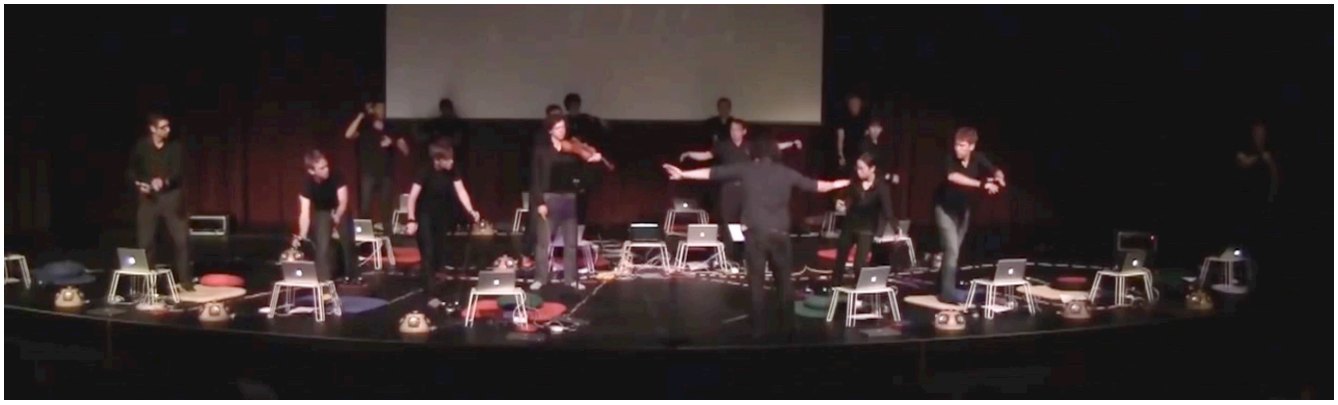

Figure 3: *Muted Voices* (2012). Still from video courtesy of David Kerr.

5. PERFORMANCE AND COMPOSITION

Since the instrument's inception in 2012, a number of works for ensemble, duo, and trio incorporating the Fragment String have been composed and performed. Initially, the Fragment String was intended as an instrument to be used by multiple performers in an ensemble, but it has since proven to work well in smaller-scale settings for two or three performers. Through these various manifestations of the Fragment String in performance and composition, the instrument has developed a broad palette of musical techniques, motives, and effects.

5.1 *Muted Voices* (2012)

The first composition to use the Fragment String was *Muted Voices* for solo violin and Fragment String ensemble (Figure 3). *Muted Voices* comprises a solo violinist and nine to eleven laptop performers with Fragment Strings. Each Fragment String samples an audio signal from the violin, mediated by a single pickup or microphone whose signal is distributed to the computer instruments. These sounds are replayed over individual six-channel hemispherical speakers situated alongside each Fragment String.

The performers are split into inner and outer groups, the former consisting of three or four performers and the latter comprising the remaining ensemble members. These groups are spatially arranged with the soloist such that the solo performer is in the center of the stage, the inner group is closest to the soloist, and the outer group is further out surrounding the inner group. A conductor leads these performers continuously throughout the piece using a set of invented gestures indicating various performance techniques of the Fragment String. The conductor is also responsible for ensuring the ensemble performers and soloist are in sync.

Compositionally, *Muted Voices* consists of eleven stanzas, each mostly under a minute in duration and each provoking the solo violinist and ensemble performers to interact in varying ways. These stanzas are arranged to support the piece's overall musical progression through ebbs and flows of sonic textures. The opening stanza of the piece utilizes one of the basic techniques of the Fragment String, gently replicating the violin's opening statement among only the inner group of performers. The next stanza brings in the entire ensemble of performers to repeat the violin's passage, and then the inner group brings in samples of the non-instrumental sound, filtering the original sample through the Fragment String, through the space, and through the Fragment String again in a sort of musical game of "telephone." These sorts of interactions are further explored in successive stanzas; near the piece's midpoint, the groups of Fragment String players perform several exchanges of samplings of the space without the solo violin, recursively filtering the ambient sound of the hall and the constituent electronic systems' own internal noise.

Overall, the work fulfilled its composer's goals of balancing both acoustic and electronic elements in a spatialized, musically meaningful interplay. A casual survey of audience reaction after the performance suggested some level of engagement with the piece both aurally and visually. Furthermore, the overall sonic textures created in the work were able to be varied to a satisfactory degree, suggesting possibilities for additional works using the instrument.

5.2 *Fragment String* (2012)

The eponymous work involving Fragment String was its debut as an instrument for a single performer within a duet, in this case with piano. The composition was again divided into eleven stanzas, each exploring different types of interplay between the piano and Fragment String. Stanzas that heavily leaned on sampling the piano were puncuated at certain points with a stanza that exclusively sampled the ambient space, complemented with droplets of piano figures, dividing the overall structure of the piece into three sections. These developed into a climax just after the piece's midpoint, in which the piano and Fragment String reached their greatest point of intensity, with the Fragment String being diffused across an 8-channel spatialization. (This is the only work thus far that has spatialized the Fragment String beyond two audio channels.)

5.3 *Side Two* (2012)

Side Two was a trio for digitally-processed guitar, laptop performer, and Fragment String, developed as an unstructured improvisation. The Fragment String's input was a mix of the guitar and a revolving sequence of unparticular patches run on the laptop, and its ability to re-render and dissect these jumbled, arbitrary sources was limited. It is difficult to view the Fragment String's role as a success in this work.

5.4 *Telematic Improvisation* (2014)

Telematic Improvisation was developed as a networked piece between a digital cello ("celletto") player in Stanford, California, and a pipa player and computer-based performers in Beijing, China. One digital performer used her custom "wheeletto" digital musical instrument, while six other performers were equipped with the Fragment String. The pipa was miked and connected to each Fragment String input, providing a backdrop for interlinking improvisations between pipa, wheeletto, and celletto.

Figure 4: *Search for Life* (2014).

5.5 *Search for Life* (2014)

Search for Life is a work for found objects and laptop ensemble (Figure 4). Two of the piece's performers construct a percussive soundscape using found objects from the streets and markets of Beijing, China, where the work was developed and premiered. These sounds are further manipulated by passive digital processing as well as six Fragment String performers, who operate the instrument with chopsticks attached to the end of each string. The Fragment String setup for each performer uses the built-in laptop microphone of its host laptop as well as an individual six-channel hemispherical speaker for sound emission, giving a localized acoustic identity to both the input and output of the instrument.

Here, the Fragment String provides a steady, unsettling backdrop to contrast with the staccato sounds of the found objects. Initially, a toy that spins a short, thin tube through the air, generating a whirring sound, is sampled by the Fragment Strings, prolonging the whirr and distributing it across the space. Later on, the Fragment Strings sample the more percussive, transient sounds of the performers, abstracting them from their mundane familiarity by examining their constituent parts.

The physical aspect of Fragment String was used to pronounced effect in *Search for Life*. After the whirring toy is sounded and carried around the space for several seconds, the Fragment String performers in unison shoot upwards, raising their arms to bring the strings to their maximum length and thus maximum volume. Similar gestural effects are employed throughout the piece, making evident the link between movement and sound.

5.6 *Improvisation for Trumpet and Fragment String* (2016)

Improvisation for Trumpet and Fragment String is an improvisitory duet between trumpet and Fragment String (Figure 5). It does not have a predefined structure or form, instead relying on dynamic listening and response on the part of both performers. In a performance of the piece in November 2016, the trumpeter put down the instrument to play via mobile phone "The Difference Between Hearing and Listening,"[1] a lecture by Pauline Oliveros, who had passed away a week prior; the audio of this recording was fed into the input of Fragment String. Overall, the piece has lent itself towards further introspection into the nature of improvisatory performance involving Fragment String.

In an acoustic chamber ensemble, the musicians will often breathe and move together, taking visual as well as aural cues as a means of anticipating and responding to one another. Although a digital musical instrument, the gestures inherent to Fragment String very closely mimic those of acoustic instruments, making it an engaging and satisfying instrument for electroacoustic collaboration.

When at rest, Fragment String is in a listening state. Much like an acoustic instrument, it produces no output until it is physically interacted with by the performer. Furthermore, it requires continuous physical input from the performer in order to produce continuous sound. Unlike some digital instruments that function autonomously after being activated by the performer, every sound produced by Fragment String is the direct result of a physical gesture. Additionally, in order to transition to new source material, at least one of the strings must momentarily return to its neutral "listening" state. This momentary reset is reminiscent of, for instance, a wind player taking a breath or a string player changing bow direction.

These acoustic instrument-like properties contrast with many electronic instruments that function by constantly producing sound, requiring a performer to carve out silence or actively stop the sound. Instead, in Fragment String as with acoustic instruments, physical gesture equals sound activation. From the perspective of the acoustic instrumentalist, this results in a natural improvisation experience; it is very easy to read the body and gestures of the Fragment String player to understand where they are going with a musical thought. This is also facilitated by the association of larger gestures with larger sounds and vice versa, a facet often overlooked in electronic music performance.

Fragment String is capable of outputting a range of sounds and gestures broad enough as to not limit the acoustic performer (by boxing them into a particular tonal center, for example). Furthermore, the ability of Fragment String to sample extra-musical room sounds and "silence" freed the trumpet player from feeling the need to drive the piece by constantly playing, or from feeling responsible for seeding new input material in order to provide musical development or variation.

5.7 *Meeting* (2016)

Meeting is an improvisatory piece for two multi-instrumentalists, one playing trumpet and Fragment String, and the other playing piano and auxiliary percussion. The piece is a slowly unfolding exploration of texture and density, making use of extended techniques and extreme dynamic range. The microphone capturing input for Fragment String is placed at a fair distance from the performers, with the goal of us-

Figure 5: *Improvisation for Trumpet and Fragment String* (2016).

[1] `https://www.youtube.com/watch?v=_QHfOuRrJB8`

ing the entire room as sampling input. This resulted in an output from Fragment String that was considerably more obfuscated than normal, in which the instruments and environmental sounds blended together to form a cloud-like wash of texture. Furthermore, this is the first and only work in which a performer simultaneously performed with Fragment String and another instrument.

During the performance, the trumpet player is seated with Fragment String positioned on the floor next to them, allowing them to interact with the strings with their left hand while holding the trumpet in their right. While perhaps not the most efficient means of playing the trumpet for prolonged periods of time, it is common practice to periodically remove one hand from the instrument in order to use mutes or turn pages, so this was a fairly natural interaction to adopt.

The main limitation of this setup is that it is difficult to take advantage of the independent control of the strings, with only one hand available to interact with them. That being said, once the strings were in the players left hand, it was possible to loop them through the 3rd valve ring (or simply thread them between fingers of the left hand) and return to a natural trumpet playing position with typical range of motion. Once engaged, even subtle movements inherent to playing the trumpet (both side to side and vertically) would pull on the strings, resulting in slight changes to Fragment Strings output.

Following the performance of this piece, a number of audience members reported enjoying the physical gestures required in order to play Fragment String. Given the results of the performance, the Fragment String offers interesting possibilities for use by a single performer with an acoustic instrument.

6. CONCLUSIONS

The Fragment String is a new digital musical instrument that samples its input and allows a performer to replay these samples using transparent, organic gestural control. Its ability to sample both instrumental sounds and the ambient noise of its electronics and environs afford it a breadth of musical expressivity. The directness and magnitude of its control interface enable it to be easily understood by beginning performers and by audiences, while allowing a depth of technique and practice to be developed with the instrument over time. These elements have been explored over a variety of works for ensemble, trio, and duo, revealing through practice the advantages, caveats, shortcomings, and future possibilities of the instrument.

7. ADDITIONAL RESOURCES

Video documentation of selected performances described above will further elucidate the ideas expressed herein. These are available at `https://ccrma.stanford.edu/~spencer/fragment-string/`. The source code for Fragment String's software is available at `https://github.com/spencersalazar/Fragment-String`.

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