Juggling for Beginners: Embracing and Fabricating Failure as Musical Expression

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ABSTRACT

In this paper, we discuss a NIME practice that incorporates juggling as a means to explore failure and playfulness in music performance. This practice develops alongside our juggling skills, creating a reciprocal relationship between designing a musical interface and learning how to use it. We first review some of the existing perspectives on error and failure in the arts. We then discuss the technical implementation of our NIME in terms of hardware, software, and sound design. Finally, we offer insights into the role of failure in our practice; first, as an unintentional artifact of learning how to juggle, then as a performative medium that we leverage for musical effect.

Author Keywords

Juggling, Musical Interface, Failure, Music Performance

CCS Concepts

•**Applied computing** → **Performing arts;** Sound and music computing; •**Human-centered computing** → *Auditory feedback;*

1. INTRODUCTION

Playfulness has historically been used in NIME design as an engagement strategy [2]. In this project, we utilize the inherently playful nature of juggling to explore the role of failure in musical expression. Our lack of prior experience with juggling created an opportunity for us to center failure as an intrinsic aspect of our design approach and our performance practice. Furthermore, since we envision future iterations of this project to involve audience participation, we considered juggling to be an approachable activity suitable for all age groups.

In this paper, we first offer an overview of prior work on the contextualization of failure as a creative artifact and the use of juggling in musical interaction design. We then describe the implementation of our project, detailing the hardware and software design of our NIME. We discuss strategies for adapting not only our sound engine but also our approach to performing with this NIME as we become more skilled with juggling over time, requiring a reframing of failure from a natural byproduct of inexperience to an expressive affordance that can be leveraged intentionally.

Figure 1: Juggling with our NIME. Left panel shows proper technique before a mistake is made in the right panel.

2. RELATED WORK

The role of failure not as an impediment but as a path to artistic discovery and self-expression has been extensively studied [1, 13]. The novelist Samuel Beckett described failure as an inextricable part of life and a critical component of creative exploration [6]. It is through repeated attempts and failures that one learns, improves, and ultimately succeeds or, in Beckett's terms, "fails better" [8].

The aesthetics of failure have been central to many practices in digital art. Failure can originate from the performance system wherein it can be contextualized as a stylistic dimension of the work [7]. For instance, the output of malfunctioning hardware or software is central to *glitch art*, a movement that is deeply rooted in music and visual media [4]. The artistic practice of "circuit bending" similarly leverages the unpredictable outcomes of misusing a system to generate sounds [14].

Much like in traditional music performance, failure in technology-mediated practices can be rooted in the actions of the performer as well. In their discussion of failure in this context, Hazzard et al. delineate how mistakes can have aesthetic consequences by way of introducing variation, interpretation, improvisation, and liveness into a performance [11]. Furthermore, they contextualize failure as a multi-layered phenomenon that spans across the intentions of the composer, the actions of performer, and the perception of the audience. Although failure in NIME performance can be challenging to parse for an audience who is not already familiar with the instrument [10], the unmistakable role of juggling in our practice allows us to leverage the aesthetic consequences of failure in a conspicuous manner.

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Figure 2: Left panel shows the battery and microcontroller with a quarter for size reference. Middle panel shows the battery and microcontroller wrapped into a module. The right panel shows the module embedded into a ball. Here, you can also see the opening that was cut into the ball.

Juggling has been previously integrated into music performance. Using inertial measurement units (IMUs) embedded in throw balls, Leischner and Husa incorporated juggling patterns into a rhythmical music generation system, where each ball is mapped to a dedicated instrument. In the mapping scheme that the authors devised, the throw rhythm derived from the average number of catches per minute controls the beat of the music, whereas the azimuth and altitude of the balls control the 360° panning of instruments [12].

Juggling as performance art extends beyond the basic actions of throwing and catching a ball. Depending on the tools used by the juggler, additional gestures, such as bouncing and rotating, can be introduced into the performance. In a project on the auditory monitoring of juggling patterns, Bovermann et al. utilizes clubs instead of balls to incorporate rotation in their sonification. Instead of embedding sensors into the props, they use a motion capture system to track the absolute position of the clubs that are rigged with infrared markers. In their sonification of the clubs, they use a sparse distribution of musical elements to avoid chaos in the layering of the sounds [5].

3. IMPLEMENTATION

We chose juggling as an expressive medium for two primary reasons: First, our lack of prior experience with juggling makes it a fertile practice for exploring the essence of failure. Second, the integral role of movement and rhythm in juggling closely aligns it with music performance. Here, we will discuss the technical implementation of our NIME, which aims to bridge juggling and musical expression.

3.1 The Ball

The most common juggling balls are bean bags. These have a low coefficient of restitution causing their movement to dampen quickly upon impact. Furthermore, bean bags conform to the juggler's hand when caught. Together, these features make them easier to juggle than some of the other juggling props. Bean bags are often made of several patches of fabric stitched together, making the insertion of an embedded system relatively easy. However, the lack of bounce in bean bags eliminates some of the more unexpected and exaggerated motion that can stem from the rebound of a ball. Unlike bean bags, stage balls have a harder outer shell often made of plastic. While these don't bounce either, they can roll when dropped. Finally, bouncing balls made of silicone or rubber can also be used for juggling. These are especially useful for juggling techniques that involve bouncing the balls off of surfaces.

Since our system is intended to leverage the artifacts of failure, we decided to work with a ball that can bounce when dropped. Furthermore, we needed our system to be easily modifiable and cost effective for prototyping. This is why we implemented our prototype with tennis balls, which are easy to source, easy to cut into, and relatively inexpensive. Even though tennis balls are depressurized when pierced, the loss of bounce was relatively negligible for our use case.

3.2 Electronics

To track the movement of each ball, we needed to design a system that involves an IMU with 6 degrees of freedom (DoF), a microcontroller that can transmit the sensor data wirelessly, and a battery unit that can power the microcontroller. Furthermore, all three components needed to be fitted in a ball that is roughly the size of a juggling ball.

Our earliest prototype utilized an Arduino MKR 1010 WiFi board and a separate 6-DoF IMU shield powered by a 2000-mAh Li-ion battery. The MKR 1010 board is 61.5 mm long and 25 mm wide. Since the outer diameter of a standard tennis ball is approximately 65 mm, the board's diagonal size exceeded the inner dimensions of the ball. We then decided to work with a Seeed Studio XIAO nRF52840 Sense microcontroller, which not only embeds a 6-DOF IMU on a 21 by 17.5 mm board but also offers Bluetooth Low Energy (BLE) communication. Furthermore, the low-energy consumption of the board allows it to be powered by a smaller battery, such as the 110 mAh Li-ion that we used. The microcontroller and the battery can be seen in Fig. 2. The software for extracting and transmitting the raw accelerometer and gyroscope data was designed using the ArduinoBLE library.

Once connected, the microcontroller functions as a BLE *peripheral device*. The code sets up a BLE service with a distinct Universally Unique Identifier (UUID). This service has a "characteristic" feature that can be read, written, and notified. This way, it can send sensor data to a BLE *central device*, in this case, our computer. In order to establish the connection between the peripheral and central devices, we used Matthew Hamilton's max-ble external.[1] When max-ble connects to a BLE service, it can subscribe to notifi-

[1] `https://github.com/mhamilt/maxmsp-ble`

cations for its characteristics. When the peripheral device detects a change in the value of a characteristic, it sends a notification to the central device with the new value. In our case, the peripheral device continuously reads accelerometer and gyroscope data and converts these into strings. These are then sent to max-ble to be further processed in Max as we describe in the following section.

Following the frugal innovation philosophy [3], we aim for this project to be easily reproducible and financially accessible. At the time of this writing, a Seeed Studio Sense costs $15.99, a 110 mAh Lithium Ion Battery costs $5.50, and a 3-pack of tennis balls costs $3.99, bringing the total material cost of our system to $68.46.

3.3 Sound Engine

The sound engine of our NIME is implemented in Max. Since the balls do not have a default orientation in which they are thrown or caught, we derive magnitude of angular rate and magnitude of acceleration from the raw gyroscope and accelerometer data. We then use these to detect throw and catch events, infer throw direction, and calculate the ball's air time. To account for the consistent Earth gravitational offset of 1G affecting the acceleration, we subtract it from the acceleration magnitude using this formula:

$$|a| = \sqrt{a_x^2 + a_y^2 + a_z^2} - 1G \qquad (1)$$

With the first ball, magnitude of acceleration is mapped to the frequency of a sawtooth wave generator. This is amplitude-modulated by a sine wave generator, whose frequency is controlled by the magnitude of angular rate. Furthermore, the time between throw events is mapped to the length of a delay applied to the sound. This creates a temporal pattern that encourages the performer to maintain a rhythm in their juggling. This also leads to interesting patterns when the performer makes a mistake. For instance, dropping a ball causes the delay time to be shortened with each bounce. As a result, the delay effect rapidly evolves from an echo to an effect that is similar to reverberation or comb filtering. Similarly, when the performer throws the ball higher, the delay time gets longer and results in phasing in the rhythmic pattern.

The second ball introduces sparse elements atop the more continuous sound of the first ball. To achieve this, we used catch events to trigger an amplitude envelope applied to a sawtooth wave generator. The length of this envelope is proportional to the air time before a catch.

Finally, the throw events for the third ball feeds an impulse into a recursive waveguide in the style of plucked-string synthesis. The resulting sound serves an intermediary role between the continuous sound of the first ball and the more transient sound of the second. However, the acceleration magnitude of the ball is proportionally mapped to the length of the delay line in the waveguide, causing the pitch of each plucking sound to shift up as the ball moves higher, creating an effect similar to the tuning of a string.

4. FINDINGS

A demonstration of our NIME can be seen in the video at this link.[2] Developing this instrument and learning to juggle were intertwined throughout our design process. Here, we will discuss how the two informed each other, prompting modifications to the sound engine on the one hand and deliberate adjustments to our performance practice on the other.

[2]`https://zeynepozcan.github.io/juggling/`

4.1 Adapting the Sound Engine

In the design of our sound engine, we started out with identical copies of the same sound source for each ball. We first followed a rudimentary sonification approach based on parameter mapping (e.g., magnitude of acceleration to oscillator frequency) to understand the relationship between sound and the movement patterns in juggling. The more chaotic nature of our juggling in the earlier stages of the project made it easier to distinguish between multiple instances of the same sound. For instance, dropping a ball or throwing it higher than intended caused it to clearly stray from the sounds of the other balls. However, as our juggling improved, the sonification approach began to yield more monotonous sounds, motivating us to explore different sound generators for each ball to further articulate their musical function.

While imbuing each ball with a distinct sound has initially interfered with the rhythm of our juggling, the transient nature of the sounds began to make it easier to focus on throw and catch events once a regular rhythm was established. Moreover, the distinctions between the sounds prompted us to imagine the musical role of each ball separately and leverage these to perform musical phrases. For instance, we began to introduce the balls one by one or juggle them in pairs to create variations in the layering of the musical output.

4.2 Failing to Learn, Learning to Fail

Learning to juggle is not unlike learning to play an instrument; the more you practice it, the better you become at it. Throughout this learning process, making mistakes is not only inevitable but also informative. One learns how to perform by failing first. Over time, failures begin to occur less frequently until a particular technique is mastered. This creates an interesting conflict between an instrument of our own design and our ability to play it. As our juggling becomes more fluid, our performance begins to lose some of the musical artifacts of failing, such as the sounds that stem from dropping the balls, bumping them into each other, or throwing them with uneven force. To mitigate this, two opportunities emerge:

1) Reworking the sound engine to make it musically expressive even when we don't fail. This requires a closer inspection of the nuances of successful juggling on the one hand, and becoming even more experienced with juggling so as to be able to perform different techniques that yield different movement data (e.g., by exerting greater control of throw distance or by bouncing the balls off of the floor or walls while juggling). Throughout our design process, the sound engine and our juggling skills have evolved in tandem to better integrate these nuances and techniques into the performance.

2) Feigning mistakes to retain some of the sonic affordances of failure. Since juggling involves developing motor skills that we don't have conscious control over (not unlike biking), the nature of the mistakes that we make can be hard to rationalize. Nevertheless, this route requires a secondary layer of performance, where the performer actively tries to make mistakes. A potential pitfall of this approach is that the mistakes may not appear as convincing as they do when they occur naturally. On the other hand, a desirable outcome of fabricating failure in this way is the ability to time them. This allows the performer to impose musical structure through the so-called mistakes.

These are not mutually exclusive approaches, as the sound engine can be modified to provoke mistakes. For instance, stochastic elements that interfere with the direct sonification of the juggling patterns can be introduced to distract the performer, prompting forced errors.

5. FUTURE WORK

Learning to play a musical instrument involves making mistakes and correcting them over time. Throughout this process, the performer improves their skill playing the instrument, which remains largely unchanged. The current project subverts this relationship by contextualizing failure as an intended feature of performance rather than one that is meant to be overcome. The design of the instrument and the performer's propensity for failure are in a reciprocal relationship, where improvements in performance prompts changes in the instrument. Our engagement with juggling as a musically expressive medium is therefore a continually evolving process where learning new techniques brings about not only new expressive possibilities but also new skill-based challenges. These challenges, in turn, lead to new modes of failure that can be incorporated into the sound engine. We will continue to grow our solo practice to further flesh out the affordances of juggling for musical expression.

We also aim to present this system in a public installation context, where the audience can engage with it in a more open-ended and playful format. To adapt the system for a public installation, we are working on a few hardware and software modifications. While BLE communication is desirable in our use case due to its power efficiency, it can also be prone to connection issues in certain applications. For instance, the human body is known to attenuate Bluetooth signals [9]. Although this doesn't pose an issue in a solo performance on stage, it can make our system susceptible to disconnections if it were to be used in a public installation where a crowd interacts with it. Therefore, we aim to implement a WiFi version of our NIME, which is not only less prone to body occlusion but can also maintain connection at farther distances. Additionally, we plan to design custom-molded silicone balls that can offer a greater coefficient of restitution while still housing the sensor system.

We also plan to work with experienced jugglers to examine how the incorporation of sound into their practice through our NIME may reinforce or interfere with their performance. Based on this exploration, we intend to leverage our system as a training tool for juggling, where sound can function as an additional feedback modality that reflects errors in technique for novice users.

6. ETHICAL STANDARDS

There are no known conflicts of interest in this project. No human subjects, besides the authors, were involved in the use and evaluation of the described system. We strove to keep the material costs of our NIME minimal within the spirit of frugal innovation. We also utilized found objects in order to reduce the material waste during the prototyping phase of our NIME.

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