RemixDrum: A Smart Musical Instrument for Music and Visual Art Remix

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***Abstract*—The remix technique has been widely used in musical practice, mainly due to the figure of Disc Jockeys (DJs), which combines several pre-existing sounds to produce completely new content. However, this creation method also appears in other forms of artistic expressions, such as architecture, photography, fashion design, video games, etc. Recent technological advances favor the emergence of gadgets that help expand this practice, such as Smart Musical Instruments (SMI), devices equipped with sensors, actuators, embedded intelligence, and wireless connectivity to allow new forms of musical expression. In view of this scenario and the versatility of remix, this paper presents a prototype of an SMI, called RemixDrum, conceived not only for creating sounds through technological means but also to allow the mixing of multimedia content, proposing a new context of use for this type of interface and a new way to make art. Finally, the prototype was evaluated quantitatively, measuring average latency, jitter and throughput, qualitatively, investigating the user experience and their interaction with the equipment, and comparatively, through an analysis between our prototype and related works, in order to analyze perceptible delays, expressiveness and other artistic factors.**

***Index Terms*—Culture of Remix, Internet of Musical Things, RemixDrum, Smart Musical Instrument**

I. Introduction

The phenomenon of remixing garnered significant attention starting from the 1970s, coinciding with the emergence of the Disc Jockey (DJ) as a pivotal figure who merged sampling techniques, consisting of utilizing sound snippets from diverse songs and recontextualizing them within novel recordings, and the art of mashup, whereby two or more pre-existing songs are combined to form a fresh musical composition. This approach found application within genres such as Hip Hop and Disco Music [1], [2].

Consequently, the notion of the Culture of Remix emerges as a term coined within communication theory, signifying cultural scenarios and lifestyles that originate from the acts of sharing, transforming, and editing preexisting works. This transformative process generates novel manifestations, encompassing new forms, concepts, ideas, and services [3], [4].

The advent and widespread adoption of Web 2.0 have led to the development of innovative tools that facilitate the exploration of remixing concepts. These tools possess inherent characteristics of flexibility and modularity, enabling new approaches to remixing [5]. A prominent example within this realm is the Smart Musical Instrument (SMI) [6], [7]. SMIs are musical instruments equipped with sensors, actuators, real-time audio processing capabilities, and wireless connectivity. Their primary purpose is to establish a means of communication between musicians, industry professionals, and the general public during live performances. Additionally, SMIs are part of a larger category of devices known as "musical things", which fall under the purview of the emerging field of the Internet of Musical Things (IoMusT) [8]–[10]. This area encompasses a diverse ecosystem of interoperable devices dedicated to the creation and reception of musical content, providing artists with new opportunities for interaction and creative expression.

Given its advantages for artistic-musical creation, this paper presents a prototype of an SMI, called RemixDrum[1], to enrich a traditional stick with sensors, microcontroller boards, and wireless connection to combine the acoustic sound of a drum with digital sounds generated from the equipment's movements, to evoke musical and perceptual experiences based on the Culture of Remix. Still, such a prototype is capable of controlling visual arts over the network, sharpening the user's creative thinking and stimulating the idealization of works that explore multimedia hybridity. We do not intend to analyze acoustic phenomena or perform any kind of retrieval of musical information in this work.

To ensure practical usability, the hardware design prioritizes simplicity, minimizing any potential disruptions to the human experience. Allied to this, the interface must meet the IoMusT

[1]Demonstration: https://www.youtube.com/watch?v=RQgIk2Z2Vxg

specifications and present interoperability and scalability, still effectively integrating sound and visual feedback.

The remainder of the paper is divided as follows. Section II provides an overview of relevant related work. Section III explains the design of the RemixDrum. In Section IV, we conducted 10 test runs with a professional drummer to evaluate latency, jitter, and network throughput. After this, a comprehensive interview assessed the user experience, and related work was examined to highlight the prototype's advantages. Finally, Section V concludes the paper by summarizing achievements and discussing future work.

II. Related Work

Despite the growing body of literature regarding smart musical instruments, there is still a gap in terms of exemplary design frameworks, particularly in the context of their application in remix and their integration with visual arts. Therefore, this section is not limited to this type of equipment but also addresses other studies that use mechanisms and concepts similar to those proposed in this work. The following paragraphs presents and elucidates those studies for a comprehensive understanding.

One prominent example in the air drum industry is the Aerodrums[2], consisting of motion sensor-equipped drumstick-like objects that accurately capture user actions and communicate them to accompanying sound synthesis software. The Aerodrums appeal to professional drummers, music producers, and drumming learners due to its compact and versatile design, besides noise reduction, suitable for live performances and studio setup [11].

Another noteworthy product is the Aeroband PocketDrum 2 Pro[3], which operates similarly to the Aerodrums by mapping user movements with two sticks to generate corresponding sounds. Its lightweight and portable design, along with Bluetooth compatibility and customizable audio samples, make it a convenient choice for users of varying skill levels.

Within academia, numerous solutions exist, many of which rely on computer vision technology. For instance, the Anywhere Anytime Drumming (A2D) system utilizes computer vision and deep learning algorithms to accurately track drumstick movements without the need for additional hardware or power sources [11]. Other prototypes following similar principles include Augmented Virtual Drums [12], Virtual Musical Instruments [13], and Air Drums [14].

Lastly, a notable case combines computer vision with elements from the Internet of Musical Things [15] to enable interactive percussion performances in networked environments. By detecting and analyzing hand, arm, and body movements, that model accurately identifies the activated drum element, offering an authentic and reliable instrument execution experience.

In light of the aforementioned context, our goal is to establish RemixDrum as a progressive iteration of traditional drumsticks. Rather than replacing conventional drum kits, this innovation integrates technological components and network communication to generate digital sound, allowing for the remixing of both acoustic and digital audio content. Furthermore, we have endowed the drumsticks with the capability to control sound effects, akin to a guitar pedal, thereby expanding the functionalities of the SMI. Notably, this model excels in real-time sound content remixing and additionally possesses the capacity to manipulate visual animations and other artistic visuals.

III. The RemixDrum Design

In the practical implementation of RemixDrum some design choices were followed, such as: i) implement a modular and adaptable architecture to connect devices; ii) incorporate two sensor interfaces: one for tactile pressure to control settings (e.g., sample activation and preset selection), and another for controlling musical parameters using spatial information (e.g., movement in the X, Y, and Z axes); iii) utilize lightweight technologies with compact dimensions for easy installation; iv) ensure extensibility through a wireless transmission system; v) achieve interoperability by leveraging standard communication protocols; vi) prioritize ease of programming and software updates; vii) and use low-cost, open-source technology.

To fulfill these requirements, ST235 capacitive touch sensors and MPU-6050 accelerometers are utilized. The ST235 device operates by modulating the capacitance of its circuit, thereby responding to changes in capacitive charge accumulation at the sensor's reference point. This modulation determines the corresponding command, such as turning an audio track on or off. The MPU-6050 model incorporates a control chip capable of measuring acceleration, rotation, inclination, and vibrations of the object. Through rotational movements along its axes, it can control sound parameters such as flanger, reverb, volume, as well as manipulate color and speed patterns in visual art.

As a processing unit and wireless access point, ESP8266 NodeMCU v2 boards were used, since its 32-bit processor provides enough computing power to capture input signals from a touch sensor and an accelerometer and send them over the network, as it also conforms to the TCP/IP protocol stack and the various IEEE 802.11 Wi-Fi standards (such as b, g, and n).

For transmitting musical information, the Open Sound Control (OSC) protocol is used, while the UDP protocol facilitates the transmission of these messages over the network. The audio synthesis and visual art creation are accomplished using the Pure Data[4] and Processing[5].

All the technologies employed in this study are based on open-source platforms[6], which enable the authors to make

[2]https://aerodrums.com/

[3]https://www.aeroband.net/

[4]Programming language and graphic environment developed by Miller Puckette in the 1990s, designed for real-time audio processing, electronic music composition, live performances, interaction with the web, and multimedia work.

[5]Created by Ben Fry and Casey Reas in 2001, it is a lightweight and user-friendly language suitable for visual works and electronic arts.

[6]Code: https://github.com/romulovieira-me/RemixDrum

updates and modifications according to their specific requirements. Furthermore, the construction of the prototype incorporated Do-It-Yourself (DIY) techniques, resulting in self-sufficiency, cost-effectiveness, and the unrestricted dissemination of the resources utilized in the creative process. Figure 1 illustrates the design, materials, and practical deployment.

IV. Evaluation and Discussion

The prototype evaluation consists of three stages. Firstly, the technical components are assessed to determine how well the system meets the network's operational requirements. Key parameters like average latency, jitter, and throughput are measured, and confidence intervals are calculated to ensure statistical reliability. The second phase of the study centers on investigating the user experience (UX) of the RemixDrum. Through the utilization of a semi-structured interview approach [16], our objective is to comprehensively explore dimensions including user-system interaction, expressive attributes, and artistic factors. By undertaking this assessment, our aim is to obtain profound insights, opinions, perceptions, and participant comprehension pertaining to specific facets associated with the instrument's design and employment. Lastly, a comparison is made between RemixDrum and similar works to highlight our prototype's advantages and contextualize its significance.

A. Performance Evaluation

To scrutinize the technical aspects, 10 test runs lasting 3 minutes each were conducted with a professional drummer. Figure 2 visually depicts the test scenario, featuring a drummer using RemixDrum in a professional studio. OSC messages, encapsulated in UDP packets, are transmitted to Pure Data for sound parameter remixing and to Processing for art modifications. Network packets were captured and analyzed with Wireshark[7]. The number of transmitted packets varied based on user expressiveness, as shown in Table I.

TABLE I: Number of packets sent by the drumsticks in each test run.

Test	Drumstick A packets	Drumstick B packets
Test 1	2630	2325
Test 2	4132	4086
Test 3	2031	2065
Test 4	1690	1447
Test 5	1708	2254
Test 6	1802	1542
Test 7	1702	1403
Test 8	1729	1393
Test 9	1835	1570
Test 10	1590	1342

In the context of artistic network performances, latency should not exceed 40000 µs (40 ms) [17]. Average latency is calculated as the difference between reception and transmission times. Jitter, representing latency variation, is measured using its standard deviation [18]. For percussive instruments that use tactile (touch sensor and accelerometer) and non-tactile (Pure Data and Processing) elements, the ideal jitter should be below 55000 µs (55 ms) to avoid noticeable impact on users [12].

Throughput, the expected number of successfully received messages within a specified time interval, is another important metric. In this work, the transmission rate of packets per second for each drumstick is examined, instead of the typical bits per second measurement. Throughput is calculated by dividing the number of packets sent by the duration of each test. Time measurement includes the period from the first to the final sample, accounting for any observed intervals between samples. All these metrics are presented graphically in Figure 3.

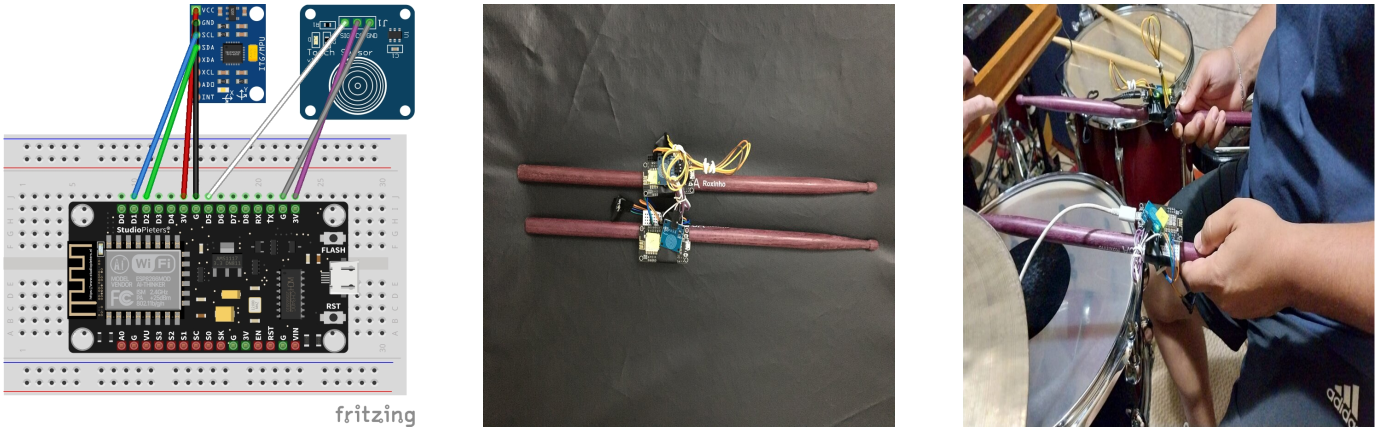
The obtained results show that the latency values are significantly below the ideal threshold for this performance type (see Figure 3(a)). Several factors contributed to this outcome, including the implementation of a dedicated network for the system and exclusive connectivity of the drumsticks to the access point. The size and content of the packets also played a crucial role in maintaining low latency. With an average size of 70 kbytes and transmission limited to supported sensor and actuator values, there were no bottlenecks or processing queues hindering transmission. Consequently, the jitter values measured approximately 46.45 µs for drumstick A and 49.07 µs for drumstick B, both well within acceptable limits for percussion instruments, as seen in Figure 3(b). The average throughput for drumstick A was 11 packets/second, while drumstick B exhibited an average throughput of 10 packets/second, as illustrated in Figure 3(c). This mitigates common issues associated with packet overload, such as network congestion, performance degradation, packet loss, inadequate prioritization, and resource exhaustion. One aspect deserving emphasis is that the Wi-Fi network employed for our tests operated within a public frequency spectrum and was susceptible to potential interference arising from coexisting networks within its vicinity. Nevertheless, subsequent investigations and amendments were not undertaken with respect to these matters, as the network in question satisfactorily fulfilled the prescribed criteria for its intended application, primarily due to the nature of the data being transmitted.

The values shown in the figure are consider a 95% confidence interval for each metric. From a practical perspective, drumstick A's average latency is expected to vary by $\pm$ 6.26µs, while drumstick B's latency is expected to vary by $\pm$ 9.34µs. Regarding jitter, drumstick A may experience variations of $\pm$ 4.64µs, while drumstick B is expected to have variations of $\pm$ 2.70µs. Lastly, the throughput variation is estimated to be $\pm$ 3 packets/second for both drumsticks.

B. User Experience

Upon concluding the technical evaluations related to the efficiency and effectiveness of the product, the focus shifted towards conducting tests on the user experience, specifically targeting hedonic qualities such as aesthetics and self-realization experienced when utilizing the instrument. The primary goal of

[7] https://www.wireshark.org/



(a) Electrical circuit design.

(b) RemixDrum prototype.

(c) Real usage scenario.

Fig. 1: Structural composition and practical application of RemixDrum.

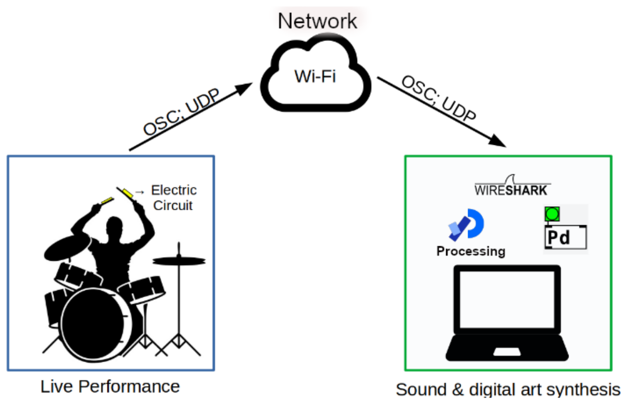


Fig. 2: Test Setup.

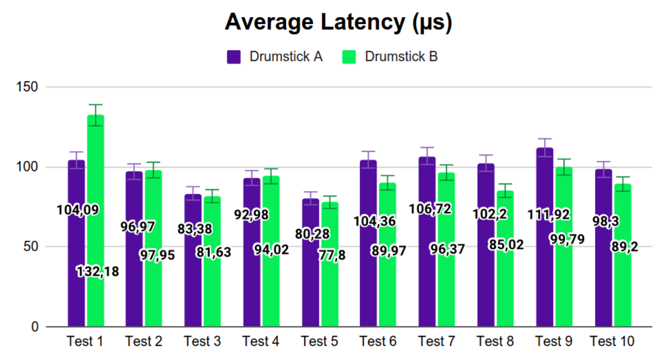
this investigation was to observe the capabilities demonstrated by a professional musician when employing the SMI and to assess the impact of its usage on artistic performances, while also gathering recommendations for potential future enhancements. The user was not assigned specific tasks but rather encouraged to verbally articulate his thoughts and reflections on their experience with the instrument, employing a modified version of the think-aloud approach based on the continuous verbal protocol [19]. This technique aimed to capture the user's internal thought processes while engaging with the equipment, fostering reflections on aspects of expressiveness, behavior, exploration, and musical creation. Upon completion of the tests, the user underwent a semi-structured interview to elucidate these topics. The interview encompassed nine evaluation aspects, as follows [20], [21]:

- **Usability:** addresses concepts such as ease of use and learning, effectiveness and ergonomics;
- **Generic UX:** uses a holistic approach and aims to evaluate the user experience as a whole, without emphasizing specific aspects;
- **Aesthetics:** focuses on the aesthetic and artistic properties of use, such as appeal, taste, style, and expression;
- **Emotion:** measures the participant's emotional responses and feelings;
- **Enchantment:** highlights the affective attention and developmental attachment to the instrument;
- **Engagement:** studies the interest and curiosity of the user towards the equipment;
- **Enjoyment:** looms large over the hedonic qualities of the interaction;
- **Motivation:** focuses on user decisions and behaviors;
- **Frustration:** underscores the pain points and obstacles faced in interaction.

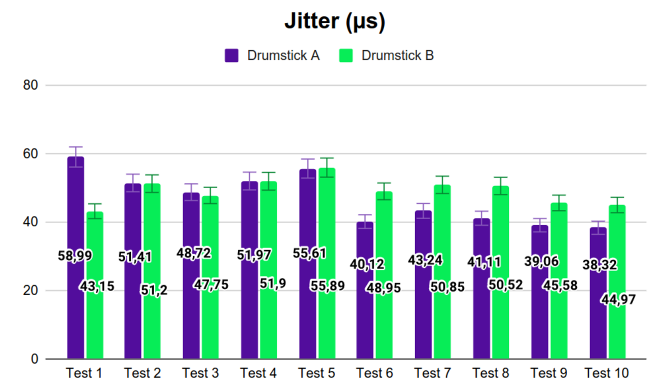
The interview included in this study, along with the corresponding responses, is presented in Table II. Both the evaluation metrics and the questions were based on works that evaluate the quality of smart musical instruments. What follows is a combination of techniques employed by different authors with similar goals in the crafting of a musical instrument, in order to investigate how this equipment allows exploring new artistic paths [20]–[23]. The questions have been condensed to conserve space, without compromising the comprehension of each evaluation metric and the user's perceptions regarding them[8]. This interview was splitted into open-ended questions and Likert scale-based inquiries.

The findings highlighted the versatility of the RemixDrum, enabling real-time processing, seamless sample switching, and playback of various audio tracks. These capabilities reduced the equipment needed for performances and minimized setup time. The instrument's ease of programming and updateability allowed for effortless transitions between presets. In terms of ergonomics, the design closely resembled a conventional drumstick, but lacked specific protective structures for the electrical circuit, which could lead to degradation over time. The user also reported discomfort due to circuit positioning during extended rehearsals or performances. While these aspects may

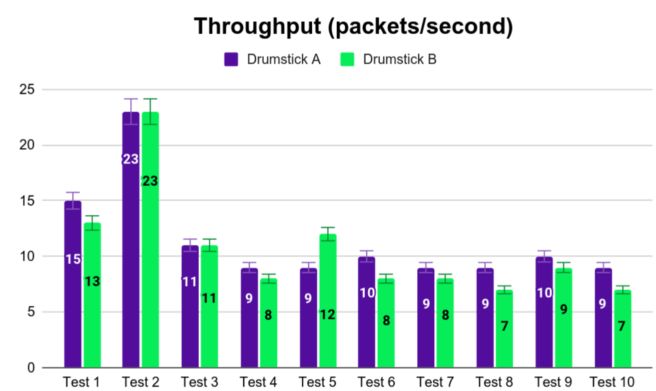
[8] Full interview guide available at: https://docs.google.com/document/d/10ND2hUA9mCWiqR36rw-YdboRh4YbxtAiYgM-RxLY-4w/edit?usp=sharing



(a) Average latency for drumsticks A and B.



(b) Jitter for drumsticks A and B.



(c) Throughput for drumsticks A and B.

Fig. 3: RemixDrum performance test results.

TABLE II: User experience semi-structured interview.

Aspects	Questions	Answers
Usability	What worked well?	Touch sensor easy to trigger. Perceived changes in movements.
	What went wrong?	Circuit positioned inconveniently.
	How easy was it to use?	Easy.
Generic UX	System working normally?	Yes.
	How is the interface design?	Good.
	Help messages provided?	No.
Aesthetics	How expressive is the RemixDrum?	Very expressive.
Emotion	How would you rate your experience?	Good
Enchantment	What skills are required in using the RemixDrum?	Prior knowledge of percussion instruments, motor coordination, agility, and musical sensitivity.
Engagement	How easy was it to adapt to RemixDrum?	Very easy.
	Instrument catch attention?	Yes.
	How strongly would you recommend this instrument?	Medium.
Enjoyment	How satisfied are you with RemixDrum?	Satisfied.
Motivation	How much effort did you put into using the Remix Drum?	Little effort.
	What is your level of motivation when using RemixDrum?	Medium.
	What aspect did you like least?	Discomfort due to circuit positioning.
Frustration	What is the most frustrating aspect?	No frustrating movements or nuances.
	What obstacles did you encounter?	Circuit positioning and power cable limitations.
Other	Comments or suggestions?	Changing circuit position and electrical supply for freer play.

not be significant obstacles, measures can be taken to protect the sensors and actuators and allow for adjustable positioning based on individual preferences.

C. Comparison with Related Work

In order to enhance the applicability of this study to the community of smart instrument designers, performers, and composers, a comparative analysis between RemixDrum and related works is also provided. This qualitative comparison is illustrated in Table III.

Based on the aforementioned information, clear distinctions can be observed between the RemixDrum and other existing models. While all models aim to replace traditional drum kits with sticks capable of simulating drum sounds through "air drumming", our prototype stands out by combining the acoustic sounds of traditional drums with digitally generated sounds from Pure Data using data captured by sensors and actuators embedded in the stick. This unique approach gives rise to a completely new form of musical expression based on the principles of Culture of Remix. Additionally, the

TABLE III: Summary of the comparison with related work.

Feature	Aerodrum[9]	PocketDrum 2 Pro[10]	Academic Models [11]–[14]	Prototype based on IoMusT [15]	RemixDrum
Goal	Create sound with the stick, removing the need for a drum kit	Create sound with the stick, removing the need for a drum kit	Create sound with the stick, removing the need for a drum kit	Create sound with the stick, removing the need for a drum kit	Remix sound and visual arts, propose new SMI applications
Operational Mode	Motion Sensors	Force, motion, and vibration sensors	Computer vision	Computer vision	Touch sensor, accelerometer
Protocols	Wi-Fi, MIDI, Bluetooth	MIDI, Bluetooth	N/A	N/A	Wi-Fi, OSC, UDP
Open-Source	No	No	N/A	N/A	Yes
Initiative	Industry	Industry	Academia	Academia	Academia

captured data is also utilized for visual arts. In summary, these functionalities represent a significant advancement in this type of equipment and introduce a novel functionality for the SMI domain, as our instrument is built upon these concepts.

In terms of operational features, the RemixDrum distinguishes itself from other models in multiple aspects. While industry-created models also employ sensors, the ones used in our prototype are different, providing a new way of thinking about the architecture of such equipment. In comparison to models developed by academia, the differences are even more pronounced as the latter predominantly focuses on visual computing techniques, necessitating more computational resources for processing information and often overlooking the expressiveness of the object used for sound generation. In contrast, the techniques employed in our gadget take an alternative direction, leveraging lightweight and robust hardware and software for artistic creation while prioritizing the aesthetics of the product to enable musicians to express their emotions through it.

Furthermore, RemixDrum is the only model in the selection that embraces an open-source approach, utilizing technologies that adhere to this principle and providing access to its codes and electronic schematics for reproduction or modification by any user. Conversely, industry-created models are protected by patents, and academic models primarily focus on image processing techniques, as previously mentioned, rather than emphasizing usability or providing means for others to reproduce their schemes.

Regarding the communication protocols employed, RemixDrum stands apart from market-oriented models by prioritizing the OSC protocol over MIDI, while Wi-Fi and Bluetooth are commonly used in both of them. Academic models, operating differently, do not necessarily rely on any of these protocols.

Guided by the principles of DIY and open-source approaches, RemixDrum is designed to be a cost-effective product. Despite its affordability, it is capable of generating sound on par with market models and even enables real-time addition of effects, making it not only a financially advantageous option but also functionally competitive. In contrast, academic models allow for the use of any object as a drumstick, but their full operation is tied to sophisticated computer vision algorithms that require substantial processing power and high-quality cameras, resulting in a potentially high price.

RemixDrum is not self-contained, as it only includes embedded sensors, processing unit, and wireless connectivity within the drumstick. The audio processing and visual content generation components operate on a separate computer within the same network. Nonetheless, this architectural arrangement does not present any inherent issues, as the distribution of tasks across multiple devices, commonly referred to as crowdcomputing, is extensively employed in the field of the IoMusT. From an artistic perspective, it is widely acknowledged that individuals engaged in the Culture of Remix can face legal repercussions for copyright infringement or violations of intellectual property laws. However, with the widespread accessibility of the Internet and multimedia systems, the notion of creating entirely "original works" has become increasingly difficult. Artists draw inspiration from and build upon the existing cultural context, reflecting the circumstances of their time [24]. It is crucial for artists to transparently acknowledge their sources and materials, even when reinterpreting the works of others. To fully appreciate these endeavors, observers must possess knowledge of the original art-pieces being manipulated. Therefore, the creation presented here is not a mere replication or appropriation of existing works but rather a celebration and reinterpretation of these artistic expressions from a fresh perspective.

V. Conclusion

Our work presented RemixDrum, a Proof-of-Concept (POC) for a smart musical instrument, which remixes multimedia content, making a significant contribution to the field of Internet of Musical Things. It offers new possibilities for artistic expression within the realm of Internet of Things (IoT) creativity. The instrument, designed as a wooden drumstick, incorporates a tactile sensor, accelerometer, integrated processing capabilities, and wireless connectivity. Its versatility enables its use in various artistic domains, such as live performances, improvisation, and composition. The modular architecture allows for flexible configurations, while distributed processing enhances its adaptability in terms of sound-related aspects.

Our study also evaluated network performance metrics of the project, including latency, jitter, and throughput. Additionally, preliminary qualitative findings regarding user experience were presented, serving as motivation and validation for further research. Although aspects like ergonomics, aesthetics, and energy supply require refinement, the insights shared in this study are valuable for designers in this field, providing a reference for subsequent prototype development and advancing the discipline.

Several limitations can be identified as potential areas of improvement, encompassing the absence of instrument ergonomics, the presence of a large and fixed electronic circuit, and the lack of user support mechanisms. As future work, we intend to tackle these points, in addition to developing this POC into a fully functional product, improving visual feedback and creating an ecosystem for musical user accompaniment and integration with augmented reality (AR). Furthermore, we intend to apply musical information retrieval (MIR) metrics to assess some specific characteristics of the audio.

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REFERENCES

[1] E. Navas, *Remix Theory: The Aesthetics of Sampling*, 1st ed. Ambra Verlag, 2012.

[2] J. Tragtenberg, G. Albuquerque, and F. Calegario, "Gambiarra and Techno-Vernacular Creativity in NIME Research," in *NIME 2021*, apr 29 2021, https://nime.pubpub.org/pub/aqm27581.

[3] J. Parsons, "Remix: Making art and commerce thrive in the hybrid economy," *Journal of Teaching and Learning*, vol. 7, 02 2010.

[4] L. Manovich, "What comes after remix?" 2007, unpublished.

[5] P. Lévy, *Cyberculture*, 1st ed. Editions Odile Jacob, 1997.

[6] L. Turchet and P. Bouquet, "Smart musical instruments preset sharing: an ontology-based data access approach," in *2021 IEEE 7th World Forum on Internet of Things (WF-IoT)*. IEEE, 2021, pp. 1–6.

[7] L. Turchet, "Smart musical instruments: Vision, design principles, and future directions," *IEEE Access*, vol. 7, pp. 8944–8963, 01 2019.

[8] L. Turchet, C. Fischione, G. Essl, D. Keller, and M. Barthet, "Internet of musical things: Vision and challenges," *IEEE Access*, vol. 6, pp. 61 994–62 017, 2018.

[9] R. Vieira and D. Muchualuat-Saade, "A survey on the internet of musical things: Environment challenges, standards, services, and future visions," in *2022 IEEE 8th World Forum on Internet of Things (WF-IoT)*. IEEE, 2022, pp. 1–6.

[10] R. Vieira, M. Barthet, and F. L. Schiavoni, "Everyday Use of the Internet of Musical Things: Intersections with Ubiquitous Music," Nov. 2020. [Online]. Available: https://doi.org/10.5281/zenodo.4247759

[11] H. Yadid, A. Algranti, M. Levin, and A. Taitler, "A2d: Anywhere anytime drumming," *arXiv preprint arXiv:2304.03289*, 2023.

[12] D. Zaveri, R. Parekh, R. Lobo, S. Ardekar, V. Vora, and A. Kore, "Aero drums-augmented virtual drums," in *2022 IEEE 4th International Conference on Cybernetics, Cognition and Machine Learning Applications (ICCCMLA)*. IEEE, 2022, pp. 516–520.

[13] S. Phon-Amnuaisuk, K. Rezahanjani, H. R. Momeni, and K. Khor, "Virtual musical instruments: air drums," in *Proceedings of the Sixth International Conference on Information Technology in Asia (CITA 2009), Kuching, Sarawak*, 2009, pp. 95–99.

[14] C. T. Tolentino, A. Uy, and P. Naval, "Air drums: Playing drums using computer vision," in *2019 International Symposium on Multimedia and Communication Technology (ISMAC)*. IEEE, 2019, pp. 1–6.

[15] A. Yaseen, S. Chakraborty, and J. Timoney, "A cooperative and interactive gesture-based drumming interface with application to the internet of musical things," in *HCI International 2022 Posters: 24th International Conference on Human-Computer Interaction, HCII 2022, Virtual Event, June 26–July 1, 2022, Proceedings, Part II*. Springer, 2022, pp. 85–92.

[16] C. Wilson, *Interview techniques for UX practitioners: A user-centered design method*. Newnes, 2013.

[17] R. Vieira, F. Schiavoni, and D. Muchaluat-Saade, "Sunflower: a proposal for standardization on the internet of musical things environments," in *Proceedings of XL Brazilian Symposium on Computer Networks and Distributed Systems*. Porto Alegre, RS, Brazil: SBC, 2022, pp. 25–32. [Online]. Available: https://sol.sbc.org.br/index.php/sbrc_estendido/article/view/21415

[18] F. Schiavoni, M. Queiroz, and M. Wanderley, "Network music with medusa: A comparison of tempo alignment in existing midi apis," in *Proceedings of the Sound and Music Computing Conference*, 08 2013.

[19] E. Krahmer and N. Ummelen, "Thinking about thinking aloud: A comparison of two verbal protocols for usability testing," *IEEE transactions on professional communication*, vol. 47, no. 2, pp. 105–117, 2004.

[20] J. A. Bargas-Avila and K. Hornbaek, "Old wine in new bottles or novel challenges: a critical analysis of empirical studies of user experience," in *Proceedings of the SIGCHI conference on human factors in computing systems*, 2011, pp. 2689–2698.

[21] D. Brown, C. Nash, and T. Mitchell, "A user experience review of music interaction evaluations," *International Conference on New Interfaces for Musical Expression*, vol. 23, p. 28, 2017.

[22] L. Turchet, "Smart mandolin: autobiographical design, implementation, use cases, and lessons learned," in *Proceedings of the Audio Mostly 2018 on Sound in Immersion and Emotion*. ACM Digital Library, 2018, pp. 1–7.

[23] S. O'Modhrain, "A framework for the evaluation of digital musical instruments," *Computer Music Journal*, vol. 35, no. 1, pp. 28–42, 2011.

[24] K. Marx, *The Eighteenth Brumaire of Louis Bonaparte*, 3rd ed. Createspace Independent Publishing Platform, 2016.