Groovuator - A Haptic Feedback System to Improve Musical Interaction Between a Drummer and a Bass Guitar Player

Kai Dehmelt[1], Pablo Alvarez Romeo[2], Mehmet Ercan Altinsoy[3]
[1] *Chair of Acoustics and Haptics, TU Dresden, kaidehmelt@posteo.de*
[2] *Centre for Tactile Internet with Human-in-the-Loop (CeTI), Chair of Acoustics and Haptics TU Dresden, 01062, Dresden, Germany, Email: pablo.alvarez_romeo@tu-dresden.de*
[3] *Centre for Tactile Internet with Human-in-the-Loop (CeTI), Chair of Acoustics and Haptics TU Dresden, 01062, Dresden, Germany, Email: ercan.altinsoy@tu-dresden.de*

Introduction

Musicians' performance during live concerts is critical to the audience's experience. In this context, the perception of the artists often varies from that of the listeners. Poor location-dependent acoustic conditions must be handled professionally so that the audience can still be provided with an impressive experience. Occasionally, due to various factors such as a noisy environment, musicians may lose track the common rhythm/tempo, decreasing the overall musical experience's quality.

Multiple systems have been developed combining music with haptics, more specifically focusing on rhythmic feedback. Pianotouch [1] focuses on musical education. As a glove aimed to improve piano students skills, it applies vibration to the fingers that should be used when learning a new song, using for that purpose eccentric rotating mass (ERM) actuators. With regards to education, there are other devices, such as the Haptic Bracelets [2] for drum students, receiving multi-limb rhythmic information from their teacher's movements or from a computer playback, and generating the corresponding vibrotactile feedback through voice coil actuators (VCAs). The Haptic Tutor [3] is also focused on drum learning, using instead ERM actuators attached to each limb. Haptics has also been implemented in metronomes. Giordano and Wanderley [4] investigated with ERM actuators its effectiveness compared to conventional ones, showing that rhythmic information transmission is possible through haptics. A commercial wristband was released by Soundbrenner [5], having currently two models, *Core* and *Pulse*, that use ERM actuators.

In this work, the focus is laid on improving inter-musician communication. In [2] it's already suggested that haptics may help in that regard. For that goal, a novel system, the Groovuator, is developed. In the next section its structure, actuation system, operation and performance will be described, followed by its use in performance experiments, and the final discussion.

Groovuator

In the previous section, multiple haptic systems that aimed to improve musical learning or rhythm have been introduced. Here, a device focused on the improvement of dynamic rhythmic information between musicians is presented. As it focuses on enhancing musical timing between users, which in colloquial language is known as grooving, this system is referred as Groovuator. In this section, it is described in terms of operation, components and performance.

System/Device

The Groovuator is a modular system designed for improving the interaction between two musicians, by measuring their interactions with their instruments, and providing haptic feedback to each other, as shown in Fig. 1.

In order to do that, each module must be able to detect and quantify the musical signal from its corresponding musical instrument, process it, and send the haptic command to the corresponding module, as explained in Fig. 2. The sound acquisition system, however, varies from one instrument to another. Here, two different instruments were chosen: a bass guitar and a kick drum of a drum set. The additional deployed system for measuring their signals is explained in the next section.

Each module is composed by an ESP32 microcontoller as core processing unit, an input stage where the input signal from the musical instrument is connected and converted with a TL072 operational amplifier to a readable value for the microcontroller's ADC, and an output stage to drive a vibrotactile actuator. This output stage is prepared in such a way that it can drive different technologies, in this case ERMs and Voice Coil actuators. For the first one, the circuit consists of a BC547 transistor, and for the second one a Class-D audio amplifier, the PAM8403, is used.

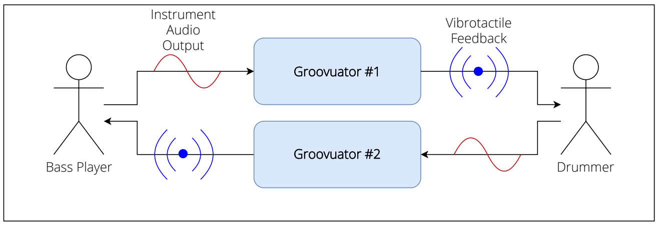

Figure 1: Block diagram of the system's intercomunication.

System's Signal Processing

Once the adjusted signal from the musical instrument is read by the ESP32, it's processed. As the read signal is produced by a musical instrument, it's expected to follow the amplitude trend of an ADSR model (Attack, Decay, Sustain and Release). It describes the envelope of an audio signal exclusively according to its amplitude,

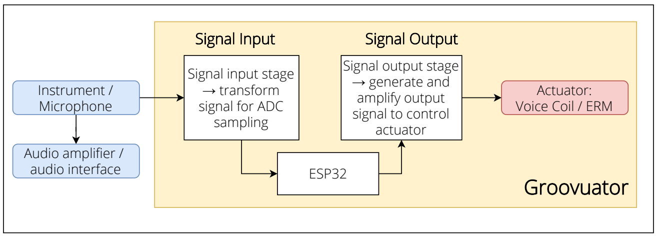

Figure 2: Block diagram of Groovuator's modular operation.

disregarding its frequency. Therefore, this model is used for detecting new events from the musical instrument. However, before applying the ADSR model for event discrimination, the envelope of the signal must be first generated from the input AC signal. For that purpose, an Envelope-Detector-Model, shown in Fig. 3 is used. Based on the model from Sethares et al. [6], it rectifies the input AC signal, using then exclusively absolute values, and applies a low pass filter which, in this case, is done by applying a Simple Moving Average algorithm.

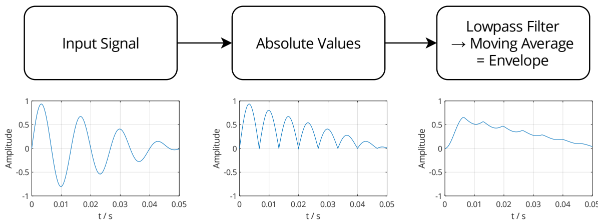

Figure 3: Envelope detector algorithm, used prior to the ADSR model.

In order to output vibrotactile feedback, two appropriate stimuli were created according to the input events produced by the bass guitar and the kick drum. While the ERM was controlled by an on-off-signal with a fixed duration, the VCAs were controlled by a sinusoidal amplitude sweep at their resonance frequency of 70 Hz. In Fig. 4 the vibrotactile feedback stimuli are displayed over time. The kick drum stimulus was chosen to last for 150 ms, according to the duration of an audio kick drum sample, while the bass guitar stimulus was adjusted to 250 ms.

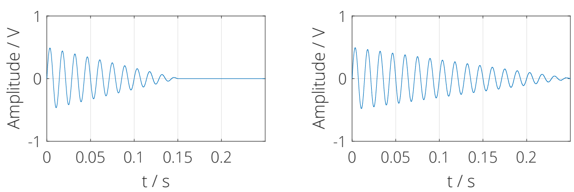

Figure 4: Vibrotactile feedback stimuli, sinusoidal amplitude sweep, $f = 70\ Hz$. Left: Kick drum stimulus, 150 ms. Right: Bass guitar stimulus, 250 ms.

Actuator Technologies

For this system various actuation systems were considered. Three were preselected for testing: a vibrating motor disc (ERM), a VCA from Tactile Labs (Haptuator MM3C), and another VCA from Lofelt (L5). In order to choose a technology for the Groovuator, a preliminary study with seven subjects, with ages between 23 and 36 years old, was realised. Actuators were attached to the lower back. At the beginning of the experiment, the subject was familiarized with each actuator by outputting the maximum vibrational intensity in each case. Next, the subject was provided with synchronised auditory and vibrotactile feedback for each pattern, playing it repeatedly for one minute, starting with the MM3C, followed by the ERM and finishing with L5. Audio samples associated with each instrument were used as audio feedback. Users were asked about four aspects, in order to rate the actuators:

- Vibration intensity.
- Correlation between audio and vibration.
- Noticeable vibration delays.
- Attributes of the vibrational feedback for every actuator.

Fig. 5 shows the answers, rated on a quality scale. The mean values of the ratings for each actuator can be found to be within the same range, except for the ERM's vibration strength perception, which was rated with lower quality. In Fig. 6 the assigned attributes are displayed in a spider plot illustrating, among other aspects, the contrast between ERM and voice coil technology, as the ERM was evaluated primarily with negative attributes, whereas the two VCAs were given a positive rating.

Users were also asked to choose the actuator that they felt produced the most appropriate vibration. According to the set of questions, both MM3C and Lofelt L5 performed well, in comparison to the ERM, which generated tickling and annoying sensations. As both VCAs performed equally well, the defining factor was the last question, about users' preferences. The MM3C won by 5 votes, compared to the 2 votes of the Lofelt L5.

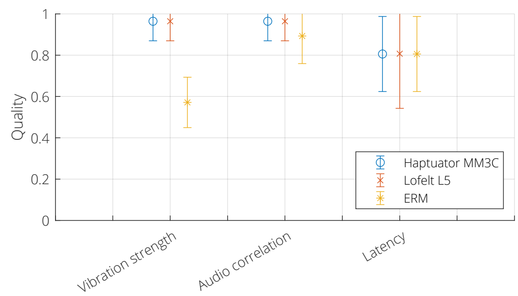

Figure 5: Mean value and standard deviation, rating the quality of vibration strength, audio correlation and perceived latency between audio and vibration.

System Latency

As the system aims to improve temporal synchronization between musicians, a controllable low latency between sound and vibration is crucial. The overall latency of the system, which includes processing the input signal, generating the driving signal for the actuator, and the actuator's start up latency, was measured with a 3-axis accelerometer ADXL335. The resulting time delay was around $t_d = 2.8\ ms$. As this time depends on the input signal's waveform, there can be some small changes

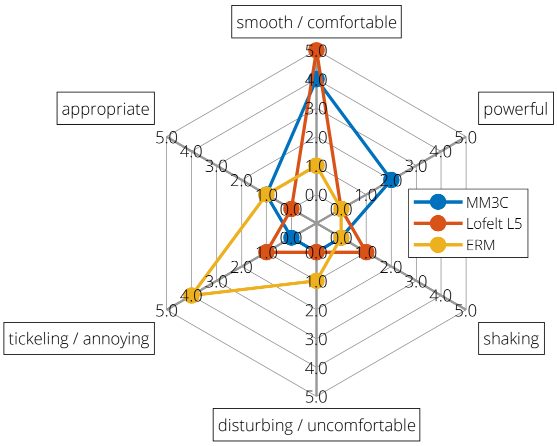

Figure 6: Rated attributes of the perceived vibrotactile feedback.

according to the dynamic audio production of an instrument. However, it can be assumed that the latency is within a range of two to three milliseconds, when using a cable connection between input and output stage. A wireless connection was not implemented at this point, but could be an improvement in order to increase the convenience of using the system. According to Altinsoy [7, 8], the onset delay of a corresponding audio and vibrotactile feedback stimulus should not exceed 10 ms to be perceived as synchronous. Therefore, the Groovuator's latency is under that limit.

Performance Experiment

To evaluate the performance of the Groovuator, experiments with test subjects were conducted. Although they presented different levels of musical experience, all of them were familiar with their assigned instruments.

Setup

For the experiment, a setup which included two Groovuator modules and two different instruments with their measurement systems, was prepared, as shown in Fig. 7. A Fender Aerodyne bass guitar and a Gretsch Catalina Club Jazz drum kit were used as musical instruments. For signal acquisition, a Behringer XAIR18 digital mixer was deployed as mixing and recording device, receiving the bass signal directly from the instrument, and the drum signal through a Sennheiser E 602 II microphone placed next to the instrument. Nine pairs of participants between the ages of 18 and 40, each consisting of a bass player and a drummer, took part in the experiment.

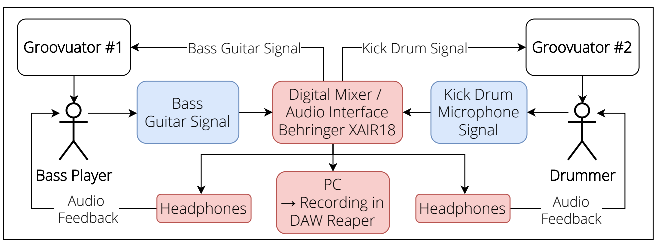

Figure 7: Measurement's setup diagram, with musical acquisition system defined.

First Part - Solo Play

The participants were asked to learn and play a simple musical pattern first. Following that, they played the pattern alongside to a playback of the other instrument. The playback was provided over headphones. Fig. 8 illustrates the experimental setup.

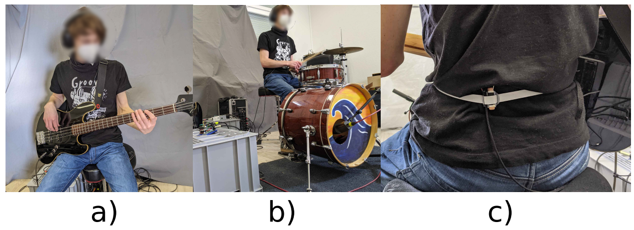

Figure 8: Musicians with the corresponding instruments. a) Bass player b) Drummer c) Actuator placed at the lower back

The pattern was then played for one minute each in 3 different modes: 1) clean audio feedback without Groovuator, 2) disturbed audio feedback without Groovuator, and 3) disturbed audio feedback with Groovuator. Disturbed audio means that a reverberation effect was added to the audio signal, which started approximately after 100 ms, and was increased in level by 12 dB in relation to the direct signal. the outputted vibrations were triggered by the direct audio signal without reverberation.

During the musical performance, the audio output of the played instrument was recorded and analysed in terms of accuracy with respect to the expected tempo and the beat grid. Mean value and standard deviation over 30 measuring points per proband and per mode are displayed in Fig. 9 for the bass guitar and in Fig. 10 for the kick drum. Considering the bass players, it can be seen that for most data points, a low mean latency with a small standard deviation is obtained for clean drum audio feedback (blue) and that they performed in the expected range of latency around $t_L = 0$ ms. The participants' performance varies slightly depending on their personal sense of timing. When the data points from the disturbed audio playback (red) are considered, distinct latencies in the direction of the reverberation signal can be noticed, which vary significantly depending on the participant. The average delay is $t_{L,Mean,all} = 50.7\ ms$. When using the Groovuator (yellow) the musician can synchronize the onsets in the direction of the direct sound. A latency of $t_{L,Mean,all} = 11.8\ ms$ is attained on average.

When looking at the analysis of the kick drum, the individual sense of rhythm per proband has influenced the measurement even more. A trend of playing to clean audio feedback is not clearly seen. A significantly stronger fluctuation of the latency can be seen over all three modes and probands. It can be noticed that the Groovuator helped especially the probands 2,3,5,6 and 9 to shift the latency while playing to disturbed audio feedback in the direction of what was measured during playing to clean audio feedback. It is assumed that the strong deviations in timing were influenced by the selected sound of the bass playback. A synthetically generated sound with fast attack and release and almost no decay made it difficult for the musicians to follow the beat grid of the playback.

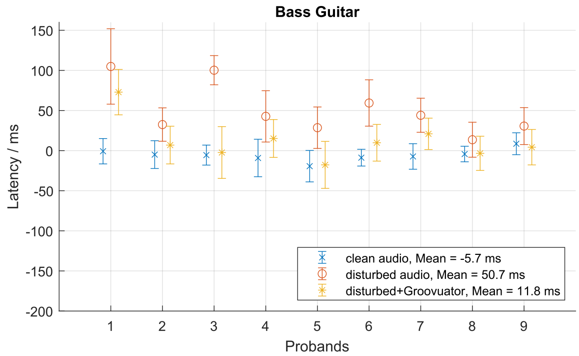

Figure 9: Mean and standard deviation of bass guitar measurements, each averaged over 30 measuring points.

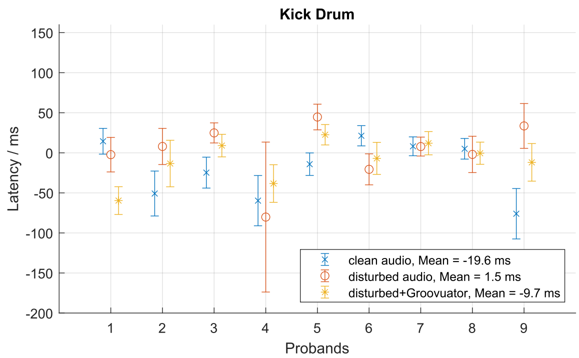

Figure 10: Mean and standard deviation of kick drum latency measurements, each averaged over 30 measuring points

Second Part - Subjective Latency Thresholds

In a final experiment, the latency threshold of the subjects was estimated to assess whether it is possible to work with higher latencies between audio and vibrotactile feedback in an extended system. For this purpose, a drum playback was played to each participant through headphones while the Groovuator delivered stimuli associated with the kick drum. The latency between audio and vibration was increased by $t_L = 2.5\ ms$ every two pattern runs. Subjects were asked to signal after subjectively detecting a latency between audio and vibrotactile feedback. Subsequently, the experiment was repeated a second time. The averaged latency thresholds of all subjects are shown in Fig. 11. The median over all latency thresholds is $t_{L,Median} = 10.5\ ms$.

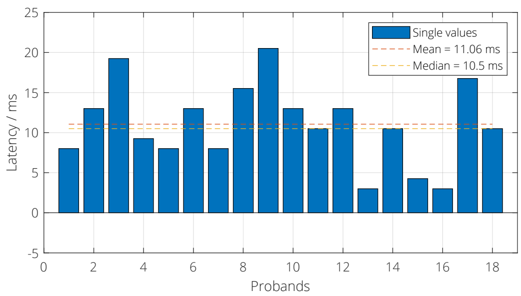

Figure 11: Subjective latency detection threshold for audio and vibrotactile feedback.

Discussion

This work investigated the development of a vibrotactile feedback device for tempo-dynamic support of two musicians. The information of the rhythm provided to the musician was obtained from the other musician's instrument. It has been demonstrated in these experiments that vibrotactile feedback, in addition to audio feedback, can contribute to a significant improvement in timing and synchronization. Bass players in particular benefited from the feedback generated from the kick drum, implicating that rhythm instruments are best suited for generating vibrotactile feedback with the Groovuator. Further improvements to the system, e.g. an improved algorithm for envelope generation, as well as more detailed series of experiments with distinctions between amateur and professional musicians could be conducted, in order to improve the performance of the Groovuator and better specify its area of application.

Acknowledgment

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