Gesture Controlled Virtual Instrument with Dynamic Vibrotactile Feedback

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ABSTRACT

This paper investigates whether a dynamic vibrotactile feedback improves the playability of a gesture controlled virtual instrument. The instrument described in this study is based on a virtual control surface that player strikes with a hand held sensor-actuator device. We designed two tactile cues to augment the stroke across the control surface: a static and dynamic cue. The static cue was a simple burst of vibration triggered when crossing the control surface. The dynamic cue was continuous vibration increasing in amplitude when approaching the surface. We arranged an experiment to study the influence of the tactile cues in performance. In a tempo follow task, the dynamic cue yielded significantly the best temporal and periodic accuracy and control of movement velocity and amplitude. The static cue did not significantly improve the rhythmic accuracy but assisted the control of movement velocity compared to the condition without tactile feedback at all. The findings of the study indicate that careful design of dynamic vibrotactile feedback can improve the controllability of gesture based virtual instrument.

Keywords

Virtual instrument, Gesture, Tactile feedback, Motor control

1. INTRODUCTION

Virtual instruments tend to suffer from lack of tactile feedback. Recently, there have been several studies attempting to solve this problem. Howard and Rimell [5] introduced 'Cymatic' – virtual instrument that can be controlled with a force feedback mouse. The instrument was based on a physical mass-spring model and provided similar vibrations to real instruments. Similarly, Berdahl et al. [3] demonstrated a platform that can be used for developing tactile virtual instruments, e.g. a virtual drum with a simulated membrane. The platform was controlled with a low cost force feedback device. Furthermore, Pedrosa et al. [9] introduced a virtual instrument implemented with a high accuracy force feedback device. In this study, different force conditions were compared. In a rhythmic target acquisition task a condition where the target attracted the pointer into it (a magnet model) yielded the best performance. Also, O'Modhrain [8] showed that a resisting force that increased with pitch improved the controllability of a virtual instrument in a melody playing task.

In the above examples, the tactile feedback was provided by a force feedback device that can, to some extent, render the physical dimensions of a virtual object e.g. virtual drum membrane. The possibilities to provide tactile feedback are much more limited if the instrument is controlled with open air gestures. This widens the range of movements that can be performed but at the same time reference points for the displacements of the hands disappear. The challenges of gesture-controlled virtual instruments were studied by Mäki-Patola et al. [7]. Although the potential of these instruments seemed attractive, the playability appeared to suffer from spatial resolution, temporal latency and lack of tactile feedback. The effect of latency on playability of virtual instruments was analyzed further by Mäki-Patola and Hämäläinen [6]. They found that in a melody playing task latencies less than 120ms did not have a strong impact on performance, but 240ms latency caused considerable decrease in performance. Adding a vibrotactile feedback to a gesture controlled virtual instrument was introduced by Rovan and Hayward [10]. In their study, vibrotactile stimulation was proposed to be modulated by displacement, velocity or acceleration. Although the approach seemed promising and very similar to our approach, their study did not examine the impact of the tactile feedback in the playability of the instrument.

In previous work, we introduced the idea of dynamic vibrotactile feedback, which could be used for augmenting the user's gestural input [1]. We placed a tactile actuator into a box with a motion sensor and we used Pure Data (PD, http://puredata.info) to drive the actuator. The principle was based on wavetable synthesis which was controlled by the angular velocity of the movement. The method allowed us to create virtual textures that could be probed with the sensor-actuator device. This approach was similar to one proposed by Rovan and Hayward [10]. The texture could be used for augmenting the gestural movements when controlling a virtual instrument. Furthermore, we used similar device and approach to render augmented reality targets [2]. The study was based on scenario in which a user was looking for information in the surrounding environment by scanning it with horizontal movements with a mobile device. If some point of interest was in the pointing direction, the device provided continuous tactile feedback. The results showed that even rather narrow targets (e.g. 10°) rendered in random locations in front of the user could be found rapidly, i.e. in less than 2 seconds. We also examined the influence of a close-to-target cue in target selection time. The cue was a smooth vibration increasing in amplitude when approaching to the target. The close-to-target cue did not improve the interaction. Instead, the participants appeared to have difficulties in determining whether the vibration was the close-to-target cue or the actual target cue.

The aim of this study was to investigate how dynamic vibrotactile feedback can be used to improve the playability of a gesture controlled virtual instrument. We used a similar approach as in our previous studies to render a stationary virtual control surface and analyzed the how different feedback conditions influenced the playing performance.

2. TACTILE VIRTUAL INSTRUMENT

Our simple virtual instrument consisted of a hand held sensor-actuator device similar to the one our previous studies. The instrument was based on a virtual control surface that was a horizontal plane in front of the player. A percussive sound was triggered when the pointing direction crossed the surface downwards.

2.1 Sensor actuator device

The motion sensor (Xsens MT9B, http://www.xsens.com) consisted of a 3D accelerometer, a 3D gyroscope and a 3D magnetometer. The magnetometer readings were discarded due to the strong magnetic interference caused by the tactile actuator. The sensor provided the orientation readings sampled at 100Hz within the accuracy of 0.1°. These values were preprocessed in a Windows application and sent to PD. The vibrotactile actuator was housed in a chassis together with the sensor. The actuator was a voice coil tactor (C2) with a peak amplitude response at 260Hz. The sensor-actuator device was connected to a PC (Lenovo T60) with a cable.

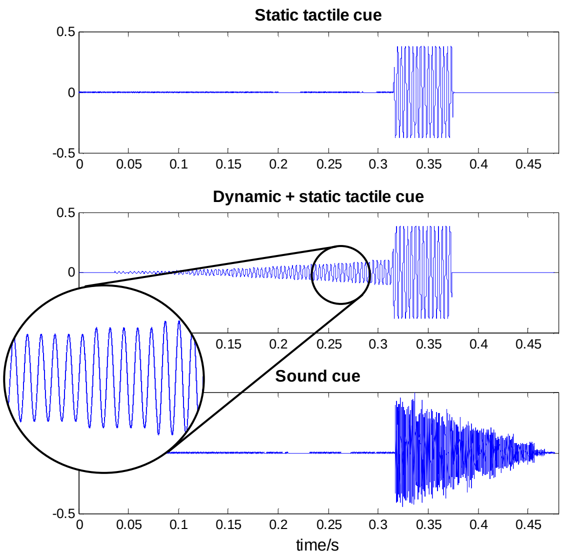

Figure 1. The tactile and sound signals triggered when crossing the virtual control surface. The illustration reflects a strike occurring with a velocity of 60°/s. The virtual control surface is crossed at 0.32 seconds.

2.2 Sound and Tactile Synthesis

The percussive sound was a simple burst of white noise with triangle shape envelope of length 150ms. The amplitude of the envelope depended on the velocity of the device in the moment of the crossing the surface. There were two tactile cues related to the virtual control surface: static and dynamic. The static cue was in synchrony with the percussive sound and rendered when the tilt angle crossed the control surface. It was a simple burst of 260Hz sinusoid with duration of 60ms. The amplitude was always the same independent on the velocity. The dynamic tactile cue was a vibration (260Hz sinusoid) increasing in amplitude when approaching the control surface, according to the following equation:

$$A=a(20-D)^2,\ D\geq 0 \text{ or } D<20°\text{, otherwise } A=0 \qquad (1)$$

where D was the distance from the virtual control surface in degrees (°). The parameter ***a*** was selected so that the maximum amplitude of the dynamic cue reached 25% of the amplitude of the static cue. The tactile cues and the percussion sound signal are illustrated in Figure 1. The signals correspond to a situation where the virtual control surface is crossed with a velocity of 60°/s.

2.3 Playing and Playability

The instrument was designed to be played in a standing position. The virtual control surface was a plane tilted by 10° upwards from the horizontal plane. The player was holding the device in her/his dominant hand and tilting the device either with the whole arm or just with the hand. The playing posture is illustrated in the Figure 2.

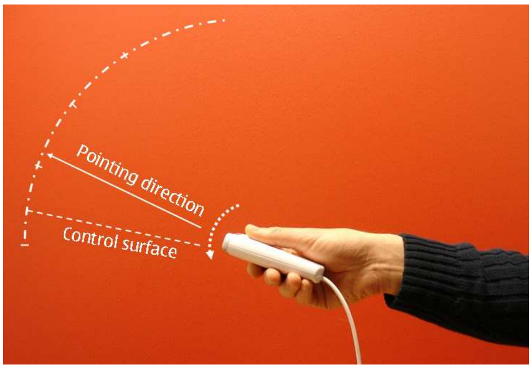

Figure 2. Playing the virtual instrument was based on a virtual control surface that was struck with sensor-actuator device. When the tilt angle of the device crossed the control surface, a percussion sound was triggered

The latency of the feedback (tactile and sound) is very relevant for the playability of an instrument. Especially with percussive sounds and rhythmic interaction the delay of the feedback influences significantly the accuracy of the control [3, 6]. In our virtual instrument, the delay between the sensory input and audiotactile output was approximately 50ms introduced by the sensor acquisition, signal processing and audio buffering. The latency was measured with a specific setup where a microphone was attached to the device surface. The device was tapped with a stick and the microphone captured the tapping sound and the following feedback, including sound and vibration. Due to the latency, the virtual control surface tended to move downwards with higher velocities. For example, if the movement velocity was 180°/s, the virtual control surface was perceived 9° lower than was actually meant to be.

3. EXPERIMENT

We designed a tempo following task for the experiment and analyzed the rhythmic accuracy and controlling of amplitude and velocity of the movement during playing. Our hypothesis for the experiment was that the dynamic tactile cue would improve the temporal accuracy. Also, we assumed that the dynamic cue would help the participant to control the velocity better. The static cue was not expected to improve the control since it did not provide any additional information to the sound cue.

3.1 Test Setup and Conditions

Six males of the age range of 30-46 participated in the experiment. They were selected based on the musical background and expected to have a good sense of rhythm. The experiment was arranged in a small office room equipped with computer, monitor and the sensor actuator device. The supervisor of the test was present in the room during the experiment. The experiment consisted of three blocks with different feedback conditions:

1. (A) Audio feedback and no tactile feedback at all
2. (AS) Audio and static tactile feedback
3. (ASD) Audio, static and dynamic tactile feedback

The blocks with different feedback conditions were conducted by each participant in a counterbalanced order (within group setup). Before each block, rehearsal block was conducted with the same feedback condition as the actual block.

The task in the experiment was to follow tempo presented by a series of short beeps played through headphones to the participant. The beeps were arranged in a 2/4 time setting where a lower beep (400Hz) corresponded to the first beat and a higher beep (800Hz) corresponded to the second beat of the measure. The task of the participant was to strike the virtual control surface on the second beat (higher beep) as precisely as possible. The sequence of beeps consisted of eighteen 6-measure sections of different tempos. The tempos were 80, 90, 100, 110, 120 and 130 bpm. The order of the tempo sections were randomized so that each tempo section was presented in a sequence three times. This way we created four different sequences. Three of them were used in actual blocks in counterbalanced manner and the fourth one was used in the rehearsal block before each actual block.

In addition to tempo follow task, the participants were instructed to keep the movement velocity low (<100°/s) to avoid the effect of latency in the performance. The velocity control was assisted by a visual bar indicator that was displayed on the monitor in front of the participant. The screen also presented the information about the test flow by a progress bar. The sound of the tactile actuator was masked with 1kHz low-pass filtered white noise that was played through the headphones. The sound pressure level was tuned so that it masked the sound from the actuator but at the same time did not mask the sound of the actual instrument or the beats of the tempo sequence. The experiment lasted approximately 30 minutes and participation was compensated by a cinema ticket.

3.2 Results

The experiment data was preprocessed and analyzed with MATLAB. Each experiment block consisted of all together 108 beats (higher beeps) and each of these beats were associated with following (dependent) variables: time difference between the beat and the virtual control surface crossing (temporal accuracy), deviation of inter-stroke intervals from tempo (periodic accuracy), velocity of the movement at the crossing moment and the amplitude of the movement. The amplitude was calculated as the difference between the highest and lowest point of each stroke. The independent variables were the feedback condition, tempo and variations in tempo. An example of an experiment session data is illustrated in Figure 3. The big triangles represent the beats of the tempo sequence and the curve represents the tilt angle of the device. The virtual control surface is presented as a horizontal line at 0°.

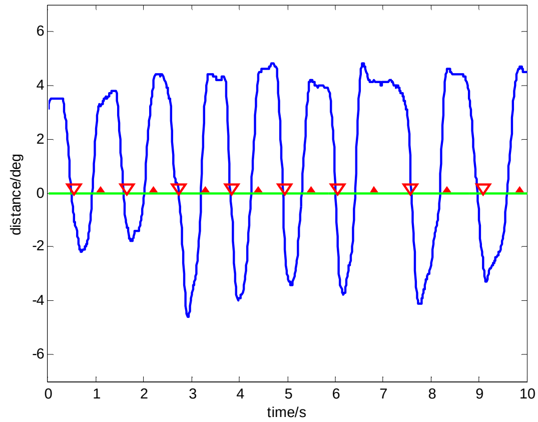

Figure 3. An example of experiment session output data. The bigger downward pointing triangles represent the higher beeps of the tempo sequence while small triangles the lower beeps. The task of the player was to strike at the higher beeps. The vertical axis represents the distance to the virtual control surface. The successful strokes are the zero crossings of the declining curve.

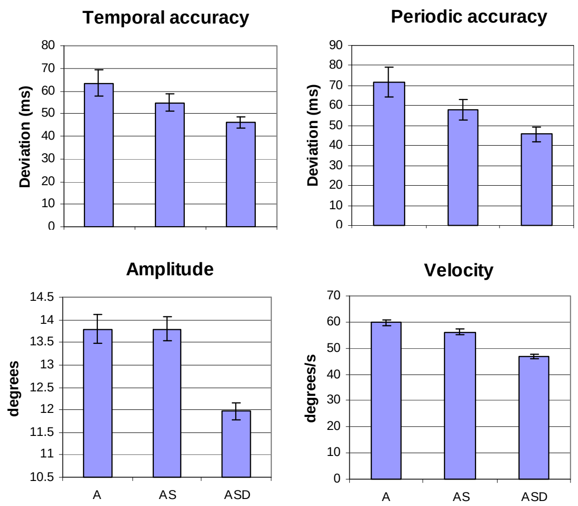

Figure 4. Temporal deviation from the beat and periodic deviation from tempo with respect of the feedback conditions are presented in top figures. Movement amplitude and velocity of the device at the moment of crossing the virtual control surface are presented in the bottom figures.

The temporal deviation from the beat was significantly effected by the feedback condition and tempo variations, while the tempo itself did not have effect. This is indicated by a 3-way ANOVA, F=4.3, p=0.014 and F=10.73, p<0.01 for feedback condition and tempo variations, respectively. The condition with both static and dynamic tactile feedback (ASD) yielded significantly the best temporal accuracy while condition with only audio feedback (A) yielded the worst. In pair wise comparison, the only insignificant difference was the A-AS pair (t-test, p=0.18). Other differences were significant (t-test, p<0.05). Similarly, condition and tempo variations had significant effect on the periodic accuracy, revealed by 3-way ANOVA (F=5.5, p<0.01 and F=23.6, p<0.01). Again, the only insignificant difference in pair wise comparison was yielded with A-AS pair (t-test, p=0.10).

The movement velocity was significantly effected by all independent variables: feedback condition, tempo and tempo variations. The 3-way ANOVA revealed the most significant interaction between the feedback condition and velocity, F=42.08, p<0.01. The condition with static and dynamic feedback yielded the lowest velocity while condition with only audio feedback yielded the highest. In pair wise comparison, all the differences in velocity between the conditions were significant (t-test, p<0.05). With respect of the amplitude of the movement, the only feedback condition had significant effect, revealed by 3-way ANOVA (F=15.31, p<0.01). The effect of feedback condition in all dependent variables is presented in Figure 4.

4. DISCUSSION AND FURTHER WORK

The results of the influence of the dynamic tactile feedback in the playability of the virtual instrument are very encouraging. Although our instrument did not provide realistic tactile feedback from the control surface as can be produced with force feedback devices [3, 9], the dynamic tactile cue significantly improved the temporal and periodic accuracy and control of the velocity of the movement. Most probably the dynamic tactile cue indicated the proximity of the control surface and helped the player to keep the device close to the surface while waiting for the next beat. The finding is different from our previous work with augmented reality target acquisition. A close-to-target cue did not assist the participants to find the targets more efficiently. The fundamental difference between these setups was that in the current study, the participant had quite accurate prior knowledge about the location of the virtual control surface whereas in the augmented reality study the targets were randomly located in space. This suggests that the dynamic tactile cue (or close-to-target cue) suits the best for augmenting the proximity to a target whose location is approximately known. Although the static tactile feedback did not yield better rhythmic accuracy over the condition without tactile feedback at all, the results suggest that even the static feedback improved the playability. In velocity control comparison, the static tactile feedback helped the participants to keep the movement slow. This is against our hypothesis since the static tactile feedback did not provide any additional information to the sound cue. This finding may be caused by the illusion of the touch to a physical surface that the static tactile cue created. The participants may have established a mental model of the surface which helped them to recall the actual position of it.

The tempo was kept rather low in the experiment; the highest tempo was 130 bpm. Because the participant was expected to strike with the device every second beat (higher beeps), in the fastest sections of the experiment the strokes occurred every ~0.92seconds. This is rather slow frequency when considering a real music performance. Therefore, due to the latencies introduced by our system, the findings may not apply for higher tempos and more frequent strokes. In the current study, the latency between the movement and actual audio and tactile output was approximately 50ms. In accurate control of a gesture based virtual instrument, a better temporal resolution should be achieved. Also the bandwidth of the tactile actuator limited the design of the tactile cues. With more expressive actuator, there would be more degrees of freedom in the design.

The instrument described in this study was very simple. It provided only one type of percussive sound while the main interest was in examining the effect of different tactile feedback conditions in playability. In further studies, the findings could be applied in more complex implementation of virtual instrument with richer selection of sounds and control parameters. For example, the tactile feedback of the virtual control surface could also be modified based on the sound model. Harder surface (e.g. tight drum membrane) with sharper sounds could also feel harder than a softer surface. Furthermore, in addition to the augmentation of virtual surfaces i.e. specific areas in space, the vibrotactile feedback could be used for augmenting the dynamic characteristics of gestures e.g. movement velocity. As we demonstrated in our previous work, the velocity could be used to create vibrotactile textures. These textures could be modeling resonances or other vibrations responding to the playing of the virtual instrument.

5. REFERENCES

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