Low Cost Force-Feedback Interaction with Haptic Digital Audio Effects

Alexandros Kontogeorgakopoulos[1] and Georgios Kouroupetroglou[2]

[1] Cardiff School of Art and Design, University of Wales Institut Cardiff
Llandaff Campus, Western Avenue, Cardiff, CF5 2YB, United Kingdom
akontogeorgakopoulos@uwic.ac.uk

[2] National and Kapodistrian University of Athens,
Department of Informatics and Telecommunications, GR-15342 Athens, Greece
koupe@di.uoa.gr

Abstract. We present the results of an experimental study of Haptic Digital Audio Effects with and without force feedback. Participants experienced through a low cost Falcon haptic device two new real-time physical audio effect models we have developed under the CORDIS-ANIMA formalism. The results indicate that the haptic modality changed the user's experience significantly.

Keywords: haptics, digital audio effects, physical modeling, CORDIS-ANIMA

1 Introduction

Recently, a Haptic Signal Processing (HSP) platform has been developed which enables musicians, researchers and developers in the field of sound and music computing to design haptic musical instruments using standard physical modeling formalisms [1-2]. Therefore a plethora of audio physical models, which have been conceived in the past using general purpose programming languages or more specialized software like the GENESIS software [3], can be implemented elegantly using common wide spread graphic programming environments like MAX MSP [4] or Pure Data [5] visual programming languages for interactive music. Interestingly, these models and particularly those based on the CORDIS-ANIMA simulation engine for dynamic phenomena [6], can be easily controlled using various haptic devices. Among them, the Phantom Premium (by Sensable Technologies) [7] consists of a well known, but rather expensive, device. During the last years, a new low cost haptic device, the Falcon (by Novint Inc.) [8], has been launched mainly targeting the broad gaming market. A recent study [9] that compares these two devices based on a Fitts' law targeting task [10], as described in ISO 9241-9 [11], showed that the Falcon has a higher damping than the Phantom, but there are no significant differences between them when taking completion time and error rate into account.

In this paper we present new real-time versions and implementations of two physical audio effect models, which provide force feedback to the performer, based on designs that have been proposed in the past [12]. An experimental study with a simple user interface has been developed which lets the users experience and compare the models with and without the force feedback using a typical and generally accessible setup with the Falcon haptic device. We use the term Haptic Digital Audio Effects to refer to sound modification algorithms that provide force feedback to the user. An article relevant to the theory, the concept and the design of haptic audio effects is currently prepared by the authors for future publication. It should be mentioned that the concept of Haptic Digital Audio Effects and particularly using a physical modeling approach proposed by the authors is novel. Therefore, the present paper aims to reveal its significance compared to other methods that do not take into account the haptic interaction within the context digital audio effects.

Similar investigations focused on examining the effects of haptic digital musical instruments can be found in the literature. Luciani et al. explored the ergotic (?) gestural-sound situation on a cello type haptic simulation [13]. O'Modhrain studied a Theremin-like interface using a haptic interface [14] and Berdahl built on this idea using programmed detents [15]. Marshall recently examined the effects of vibro-tactile feedback on digital musical instruments [16]. In the present user experience study, the participants are called to rate characteristics which describe the interaction with the proposed haptic digital audio effects. All these investigations, including the present one, confirmed that in digital musical instruments, haptic interaction enhances the user experience and produces promising results regarding the music interaction.

2 Models

The two novel digital audio effects *Tremolo Model* and *Switch Model* we have developed modify the amplitude of the processed sound in a physical way. The models incorporate an appropriate system structure that supports the physical instrumental interaction paradigm [17] by providing the necessary gestural/haptic input-output ports. The CORDIS-ANIMA (CA) modeling and simulation system, which is based on the mass-interaction physical modeling approach [6], has been employed for both digital audio effects, presented here in a brief way. The reader who wishes a better understanding of the technical aspects of the proposed digital audio effects is advised to consult the work presented in [12] which offers more details related to the algorithm and the modeling formalism.

In CA formalism a physical object is modelled as a modular assembly of elementary mechanical components [6]. Hence it is straightforward to represent the model as a topological network whose nodes are the punctual matter elements and the links are the physical interaction elements. The simulation space used for sound and musical applications is limited to just one dimension. Forces and displacements are projected on a single axis, perpendicular to the network plane. The Figures 1 and 2 represent the haptic digital audio effect algorithms by their topological CA network (the black disks represent the material points and the transparent ovals the interactions) combined with common signal processing block diagrams. They can be directly implemented in MAX/MSP or Pure Data with the Haptic Signal Processing platform.

The CA *Tremolo Model* is a physical realization or interpretation of the amplitude modulation / ring modulation process for low frequency carrier-signals [18]. For the range of frequencies less than 20Hz, this audio effect is called tremolo. The model uses simple simulated mechanical oscillators, nonlinear springs and it is passive. This feature guarantees the energetic coupling between the user and the system, which is essential for the instrumental interaction.

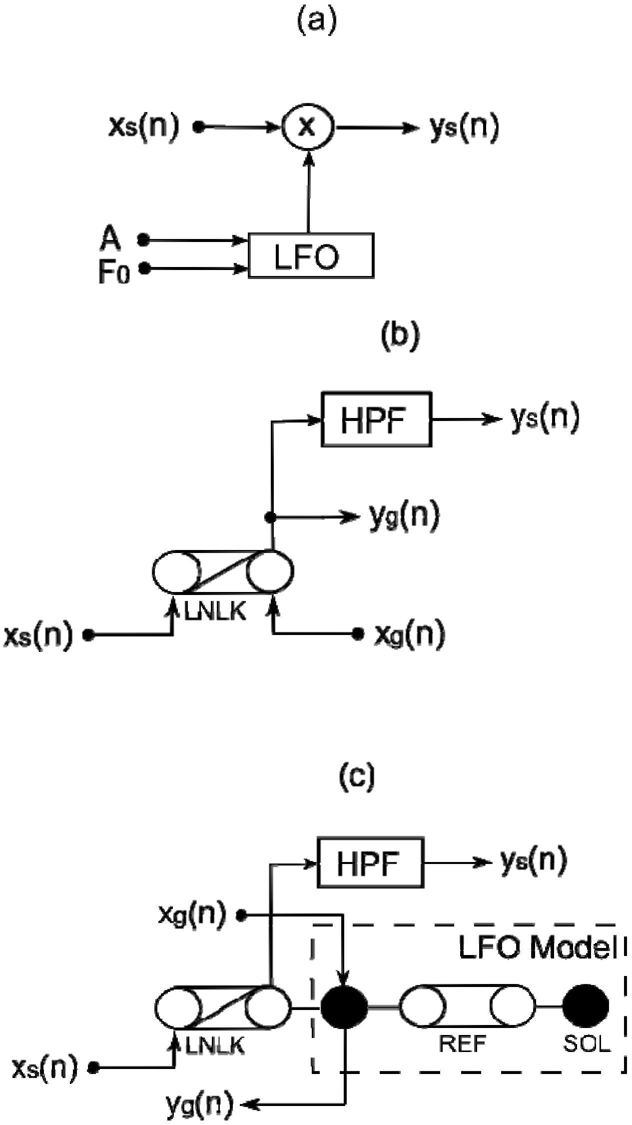

Fig. 1. Tremolo (a), CA tremolo model without an LFO model (b) and CA tremolo model (c). x_s/y_s: input/output sound signals, x_g/y_g: input/output gestural signals, A: oscillator amplitude, F_0: oscillator central frequency)

In the CA *Switch Model*, our concept was to provide a physical model that implements an ON/OFF amplitude switch. The algorithm exhibits similarities with plucked stings or plucked oscillator models, like a hand that "holds" a sound. As an illustrative example of this concept, we can imagine a hand that holds a speaker (massless in this model) and "attach" it to a vibrating structure that diffuses it as the resonance box of stringed musical instrument, like a guitar. As with the *Tremolo Model*, it uses a nonlinear spring and it is passive.

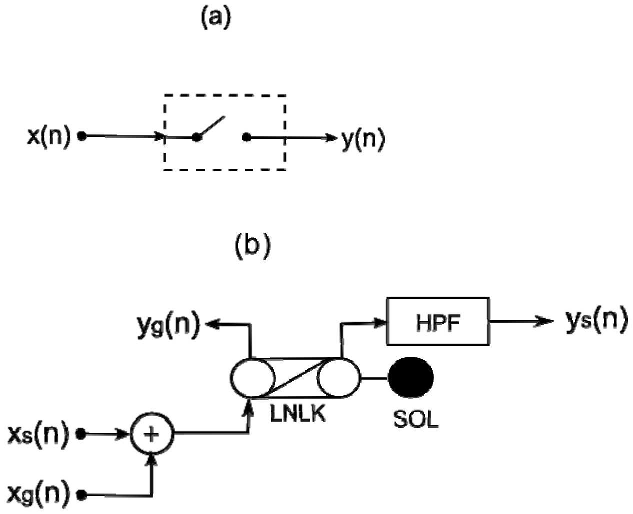

Fig. 2. A simple ON/OFF switch (a) and CA switch model (b). x_s/y_s: input/output sound signals, x_g/y_g: input/output gestural signals)

Both digital audio effects have been implemented with MAX/MSP and interconnected with a single haptic interface. The Novint Falcon haptic interface we have used (Fig. 3) constitutes a commercial, ground based, impedance haptic device [8]. It simulates mechanical impedance, i.e. it senses position and commands forces. It provides a 3D working space with three Degrees of Freedom (DOF). It has a size of approximately 10cm x 10cm x 10cm, a position resolution 400dpi and force capabilities greater than 9N. It communicates with the computer through the Universal Serial Bus (USB 2.0). Falcon is a mass-market haptic device; hence it uses rather low cost actuators and sensors, and exhibits several types of nonlinearities, such as friction and considerable backlash in the joints. However, for the purposes of our experiments on interacting with simple digital audio effects, it fulfils our specifications. The grip of the interface appears as an external object in MAX/MSP.

In Figure 4 we illustrate the simplest MAX/MSP implementation of the *Tremolo Model.* The *Switch Model* is illustrated accordingly in Figure 5. A very basic graphic user interface has been designed which gives the possibility to the users to select the audio tracks, modify their levels and control the stiffness and the friction of the audio effect models.

Fig. 3. The Falcon haptic device (by Novint Inc.)

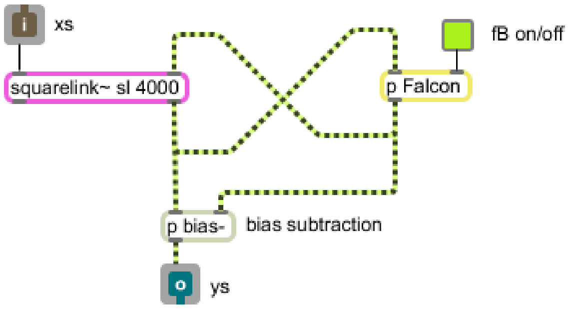

Fig. 4. MAX/MSP patch for the tremolo model

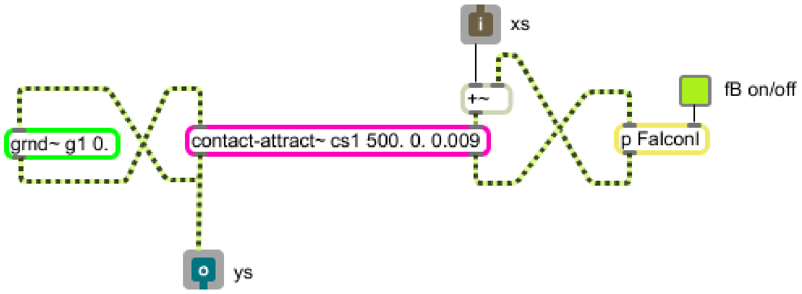

Fig. 5. MAX/MSP patch for the switch model

3 User Experience Study

A preliminary research was undertaken to evaluate the user experience with a small number of participants. The goal was to identify if the proposed system was easier, more accurate, more musically expressive and more pleasant with the force feedback enabled in the user physical interface. In order to acquire information about a person’s response when using the proposed musical signal processing algorithms, participants were asked to give their opinion scores (in a 1 to 5 scale; 1=disagree and 5=I completely agree) on a simple questionnaire after the completion of each of the following tasks:

Task 1: Try to increase or decrease the sound intensity of the music track rhythmically by using the three-dimensional Falcon device and the *Tremolo Model*. Repeat the test as many times as you want, by activating and deactivating the force feedback consecutively and by changing the tempo of the track. Do not stop holding the joystick during the tests because its purpose is to vary the intensity continuously.

Task 2: Try to "tune" the device right in order to hear clearly the music track by using the three-dimensional Falcon device and the *Switch Model*. Then turn on and off rhythmically the musical piece ("tune" and "detune"). Repeat the test as many times as you want, by activating and deactivating the force feedback consecutively and by changing the tempo of the track.

Before the beginning of the experiment, the participants were introduced individually to the haptic device and the graphic user interface, and were informed about the experiment and the scope of the designed system. Moreover they were given a small demonstration. Then they spent approximately 15 minutes performing with it and filling out the questionnaire. During the tests they were free to ask questions and accomplish the previous tasks in any order. At the end of the process they were asked to modify the stiffness and the level of the music signal entering the physical model. These two parameters alter the quality of the gestural interaction.

We should mention that our design goal regarding the proposed audio effects was not just to give to the user notable haptic tricks correlated arbitrarily with the audio processing algorithms but to design a system that has subtle instrumental qualities. The role of the energetic exchange between the instrument and the instrumentalist is emphasized even in the simple cases of the presented digital audio effects. We were not trying to evaluate a haptic display that gives haptic feedback to the user about the state of the audio effects, but a virtual causal mechanical system that processes the amplitude of the sound.

The experimental apparatus included only a Novint Falcon haptic device connected to an Apple MacBook Laptop running Mac OS X version 10.5.8, MAX/MSP Ver. 5 along with a pair of low cost studio monitors. The sound files used during the experiment were of various tracks from the electronic popular music genre. The chosen environment for the tests was a home studio. We chose to do so because we wanted the subjects to evaluate their experience in an environment that they would normally use the system.

Five male participants and one female, all active musicians and musical performers, volunteered for the study. Their age range was 31 to 34 years (mean 32.3). All had normal hearing and were right-handed. None of the participants had any previous experience with the Falcon haptic device. Moreover, participants took part in a one hour group discussion regarding their experience at the end of the session. Table 1 presents the overall results of our study for all the participants (Mean Opinion Score). The results were analyzed using common spreadsheet software.

We must mention that previous to the presented user experience test, another test took place in a human computer interaction research laboratory in the University of Athens with a small number of non expert users. It became evident though that users with no music performance experience at all would not contribute any valuable knowledge to our research. Therefore, we did not use and consider any result coming from this first session.

4 Results and Discussion

As we can observe from Table 1, the participants responded very positively regarding the use of force feedback in presented simple digital audio effects. The clearest result was that the force feedback made the effects more entertaining. Besides the fact that we should not consider the musical instruments as toys, this can still be considered as an encouraging outcome. We might assume that since an instrument is more entertaining, the users will find themselves more engaged with it and will want to explore it further.

One interesting result was that the participants did not find it easier to modify the sounds with the force feedback (see results table), however, they could modify the sounds more accurately. This is not a surprising result since virtuosity in acoustical musical instruments demands hard work and long-term commitment and dedication from the instrumentalist but it awards fine control and precision

Finally, according to the analysis, the participants found the interaction with the force feedback version of the digital audio effects more musically expressive. The results indicate that the force feedback gives richer qualities of touch, which leads to more expressive articulation of the musical ideas. This should be considered the most significant result since all digital musical instruments arguably lack this quality which, however, is essential to music.

Table 1: Results of the user experience study.

	Mean Opinion Score	
	Task 1	Task 2
It is musically more expressive to modify the sounds with the force feedback rather than without it	3,2	3,0
It is easier to modify the sounds with the force feedback rather than without it	2,5	2,2
It is more pleasant to modify the sounds with the force feedback rather than without it	3,5	3,8
It is more accurate to modify the sounds with the force feedback rather than without it	3,2	3,0

During the user experience tests and during the group discussion session upon completion of the tests, a number of interesting points were raised which concluded the evaluation of the proposed digital audio effects.

First of all the parallel linkage of the kinematic structure of the device appeared to be problematic. We were aware before the tests that a single handle with 3 active translations is not the best physical interface to interact with proposed haptic digital audio effects. During the tests, the users were confused with mechanical configuration of the interface and with the inertia of the handle. They claimed that a system with structural transparency and fewer degrees of freedom would be preferable. Since only one degree of freedom has been employed for the manipulation of digital audio effects, the physical workspace appeared to be unusual to them in the beginning. Probably a less generic interface like a simple motorized fader would be more appropriate to control haptic digital audio effects.

The vibro-tactile feedback transmitted from the grip to the hand of the participants proved to be beneficial for the feel of the instrument. This was a quite unexpected result since our design was principally focused on the force-feedback interaction and less on the vibro-tactile response. Very recent research on the examination of the effects of vibro-tactile feedback on the feel of a digital musical instrument showed an increase in performer engagement with the instrument but also a reduction of the perceived control [16].

It became obvious to us that it is difficult to evaluate the “performance” of an instrument with simple limited duration user tests like the one we employed in our present research. The instrumentalists must improve their skills with the instruments. This means that long term experimentation and test must take place in order to get more informative results about the proposed haptic digital instruments. How can you evaluate a violin in 20min if you have never tried to play it before? On the other hand, we realized that when the participants concentrated on the behavior of the effects and engaged with the task, even after the first ten minutes of the tests, they started feeling and enjoying the subtle mechanical qualities of the proposed designs.

5 Conclusion

The proposed implementation of the *tremolo* and the *switch* digital audio effects offer the opportunity to experience and perform such a simple musical sound transformation system in a novel instrumental and mechanical way. It was evident that the haptic modality changed and improved the user's experience significantly; we believe that it will possibly affect, ameliorate and generally enhance the experience of electronic music performances based on digital audio effects. The importance of instrumental and haptic control in the proposed digital audio effects must be verified in the future by similar methods to those presented, but using longer term formal observations and experiments as well as by less formal/less controlled conditions such as during a musical performance. A music piece and a performance using haptic musical instruments with the Falcon haptic interface is currently prepared by the authors and another musician and researcher in the field of haptics. We strongly believe that the planed performance will provide useful insights related to the use of haptics in music performance.

References

1. Berdahl, E., Kontogeorgakopoulos, A., Overholt, D.: HSP v2: Haptic Signal Processing with Extensions for Physical Modeling. In: 5th International Workshop on Haptic and Audio Interaction Design - HAID, Copenhagen, pp. 61-62 (2010)
2. Berdahl, E., Niemeyer, G., and Smith III, J.: HSP: A Simple and Effective Open-Source Platform for Implementing Haptic Musical Instruments, In: 9th International Conference on New Interfaces for Musical Expression - NIME, Pittsburgh, PA, pp. 262-263 (2009)
3. Castagne, N., Cadoz, C. : GENESIS: A Friendly Musician-Oriented Environment for Mass-Interaction Physical Modeling. In: International Computer Music Conference - ICMC, Goteborg, Sweden, pp. 330-337 (2002)
4. MAX/MSP http://www.cycling74.com
5. Puckette, Miller Smith: The Theory and Technique of Electronic Music. World Scientific Press, Singapore (2007)
6. Cadoz, C., Luciani, A., Florens, J.-L.: CORDIS-ANIMA: A modeling and Simulation System for Sound and Image Synthesis – The General Formalism. Computer Music Journal, 17(1), 19-29 (1993)
7. Sensable Technologies Phantom, http://www.sensable.com
8. Novint Falcon, http://home.novint.com/
9. Vanacken, L., Joan De Boeck, J., Coninx, K.: The Phantom versus the Falcon: Force Feedback Magnitude Effects on User's Performance during Target Acquisition. In: Nordahl R., Serafin S., Fontana F., Brewster S. (eds.) HAID (2010), LNCS, vol. 6306, pp. 179-188. Springer, Heidelberg (2010)

10. Fitts, P. M.: The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 47(6), 381-391 (1954) Reprinted in Journal of Experimental Psychology: General, 121(3), 262-269, (1992)
11. ISO: Ergonomic requirements for office work with visual display terminals (vdts)-part 9: Req. for non-keyboard input devices. Technical Report 9241-9 (2000)
12. Kontogeorgakopoulos A., Cadoz, C.: Amplitude Modification Algorithms using Physical Models. In: 124th Audio Engineering Society Convention, Amsterdam, (2008)
13. Luciani A., Florens J.-L., Couroussé D., Cadoz C.: Ergotic Sounds A new way to improve Playability, Believability and Presence of Digital Musical Instruments. In: 4th Int. Conf. on Enactive Interfaces, pp. 373–376 (2007)
14. O'Modhrain. S.: Playing By Feel: Incorporating Haptic Feedback into Computer-Based Musical Instruments. PhD thesis, Stanford University, Stanford, CA, USA, (2000)
15. Berdahl E., Niemeyer G., Smith III, J.: Using Haptics to Assist Performers in Making Gestures to a Musical Instrument. In: 9th International Conference on New Interfaces for Musical Expression - NIME, Pittsburgh PA, pp.177-182 (2009)
16. Marshall T., Wanderley M.: Examining the Effects of Embedded Vibrotactile Feedback on the Feel of a Digital Musical Instrument. In: 11th International Conference on New Interfaces for Musical Expression - NIME, Oslo, Norway (2011)
17. Cadoz C., Wanderley, M.: Gesture-Music. In: Wanderley M., Battier M. (eds.) Trends in Gestural Control of Music, IRCAM – Centre Pompidou, pp. 71-94 (2000)
18. Zoelzer U. (Ed): Digital Audio Effects. John Wiley & Sons Ltd, (2002)