Acoustic Optimization of Rotary Switches

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Introduction

This is the format template for creating a contribution to the conference proceedings for NAG/DAGA 2009 in Rotterdam, Due to the complexity of modern car's on-board systems car manufacturers tend to use menu based user interfaces which offer a relatively low number of control elements for a large number of functions. Since cars nowadays are no longer sold simply as technical but as lifestyle products it is crucial for the success that the potential customer perceives every single aspect of the car to be valuable. Since the user interface of the car can be judged even before a test drive the feeling of buttons and switches is a key aspect. This feeling is affected by both haptical and acoustical feedback of operation. Furthermore, a clearly perceiveable tactile and auditory feedback of successful operation improves the secutiry of operation of the car as the driver does not have to check visually if a function has been activated.

This work describes an enhanced interactive simulator for the acoustic feedback of control elements and discusses the results of a test series conducted with it. The simulator is a rotary switch on which the acoustic feedback is freely programmable. Furthermore the methods to create the stimuli used in this test will be described.

Important

There are two fundamentally different types of mechanical control elements which are commonly used:

- Tact switches
- Rotary swtiches

This work focusses on the latter.

Generally the user has several ways of realizing that he successfully used a control element. Apart from the visual feedback on a display tactile and auditory stimuli provide feedback. As Hötting [4] indicates, the acoustic feedback may dominate the impression of a successful operation of a control element. A clearly perceiveable auditory feedback signal therefore improves the security of operation of a menu-based user interface. However there is also the need to aesthetically opzimize the feedback since both Tractinsky [8], and Kurosu [5] indicated that the performance of users increases with aesthetically pleasant interfaces. Furthermore a pleasant acoustic feedback provides an opportunity to improve the perceived quality of the product.

The the subjective evaluation of both the acoustic and the haptic perfomance, programmable interactive simulators of control elements have been developed at Heilbronn university ([7], [9]). Furthermore measurment equipment for objective rating and data acquisition has been built [11].

Previous Work

Acoustic feedback signals ("clicks") recorded using the measurement system can be directly used as stimuli on the acoustic simulator. In a previous stage of tests this has been done with eight sounds which were selected by a panel of experts. These sounds were typical for the acoustic impression of certain types of rotary encoders. The picked sounds were subsequently rated by unexperienced listeners using paired comparisions [10]. Since the preference of certain sounds proved to be amplitude-dependant, the amplitude of the sounds was normalized for a second test series. This test used synthetic sounds which were based on a simple waveforms and noise, modulated by an amplitude envelope with constant linear attack and decay times. The results pointed out that subjects rejected tonal waveforms and preferred stimuli based on noise. The rejected signals were described as videogame-like and obviously synthetic.

Synthesizer

For this reason a more realistic approach was implemented. The synthesis algorithm is based on an algorithm for auditory icons proposed by Gaver [3]. Based on MacAdams' work regarding the importance of the attack phase [6], he proposed model (see Figure 1) was extended by the possibility to change the attack time of the stimulus. Furthermore the oscillators were changed from sine oscillators to programmable wavetables.

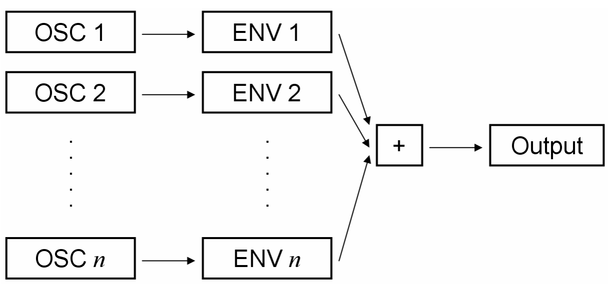

Figure 1: Principal block diagram of the synthesis algorithm. Freely programmable wavetable synthesyzers are used.

Due to the noise like character of real mechanical feedback sounds narrow band noise has been implemented as one possible wavetable. During pretests this wavetable proved to be effective. The wavetalbe synthesizer has been implemented in Matlab. It is now possible to synthesize stimuli which can be manipulated in the following parameters

- attack time
- decay time
- peak amplitude
- spectral composition
- high-frequency damping

The spectrum in itself consists of frequency, phase and amplitude for each oscillator as well as the number of oscillators. The simuli used in this examination consisted of 20 oscillators hence 60 parameters. Attack and decay time are measured from the start of the stimulus until the peak value is reached and from the peak value until the signal is reduced by 60 dB. The attack phase of the signal is logarithmic, the decay exponential (see Figure 2). High frequency damping is a factor which shortens the decay times for high frequencies.

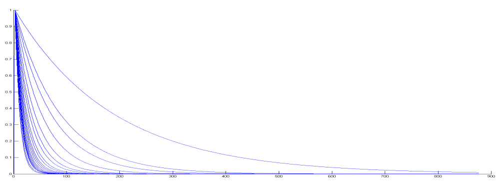

Figure 2: Example of a series of amplitude envelopes. The envelope on top is the fitted model of the decay time. All curves below show faster decays due to high-frequency damping.

According to the input data mentioned above, the noise wavetalbe is resampled to the required oscillator frequency and then multiplied by the respective amplitude envelope. Finally, all oscillator signals are summed up and multiplied to match the desired peak amplitude.

Data Analysis and Generation of Stimuli

In order to acquire realistic values for the synthesis of stimuli, three different types of rotary switches have been examined using Matlab. A database of at least several hundred clicks of each type has been analysed and resulted in a typical spectrum for each type as well as overall 5 and 95 percentiles for both attack and decay times. The attack times were set to 1ms and 4 ms, the decay times to 9 ms and 32 ms respectively, as can be seen in Figure 3.

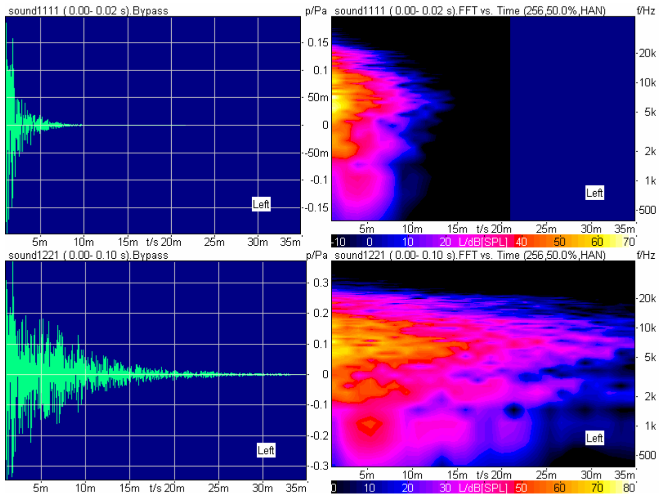

Figure 3: Two examples of synthesized stimuli. The upper signal uses fast attack and decay settings, the lower signal uses slow settings. Spectral composition and damping are the same for both stimuli.

Furthermore two arbitrary damping factors (0.01 0.1) have been selected in a pre test. Each spectrum was used with both attack and decay time and both damping factors resulting in 24 different stimuli.

Interactive Simulator

While the first two test series were paired comparisons the number of stimuli prohibit this approach in this test since. Moreover, the perceifed quality had to be judged using a nine point scale. The playback simulator had to be revised to meet the requirements for the new test layout. The combination of a rotary encoder which generates MIDI events for a hardware sampler has been replaced by a rotary encodes which communicates with a PC via RS232 using an efficent custom protocol. Output from the PC is done using a RME Hammerfall board which allows latenciey below 10 ms. The system latency from the moment of triggering the sound to playbay can therefore comply with the thresholds for audio-tactile asynchronity as stated by both Altinsoy [1] and Begault [2]. This allows the acoustic simulator to be linked with the haptic simulator for cross-modality examinations.

The PC runs a realtime software sampleplayer which receives the data from the encoder and triggers according samples. The sampleplayer has been implemented using Pure Data extended. The Pure Data program also provides the interface for entering responses via touch screen (see Figure 4). The software concept allows to use different samples for clockwise and counterclockwise operation of the encoder as well as for each individual detent.

Figure 4: Test subject using the simulator.

Apart from a change in sound playback instrument and data recording also the electroacoustic transducer has been replaced and moved.

The responses are subsequently transmitted to Matlab. The Matlab software runs the data recording as well as the control of the test sequence. Within the current test Matlab only provided pre-prepared samples for the Pure Data application, but near realtime synthesis of samples (i.e. within a test using adaptive methods) is possible as well.

Communication between Pure Data and Matlab is implemented using TCP/IP, a suitable server application has been implemented in VVVV.

Analysis of Test Results

The stimuli were presented to the 21 subjects three times in one sesstion. The order of the stimuli was randomized and the same for every subject. The subjects were free to listen to each sound as long as they wanted before responding. At the end of a test sequence the subject's answers were normalized so that each subject made use of a scale ranging from 0 (least acceptance) to 1 (maximum acceptance). The responses of all answers from all subjects to one particular sound were subsequently averaged, resulting in an average acceptance score for each stimulus.

The decay time had the biggest effect on the acceptance of the stimuli (see Figure 5). The sounds with the 9 ms decay time achieve and average acceptance of 0.66 which is the highest score of any particular group of sounds while the long-decaying sounds achieved 0.41.

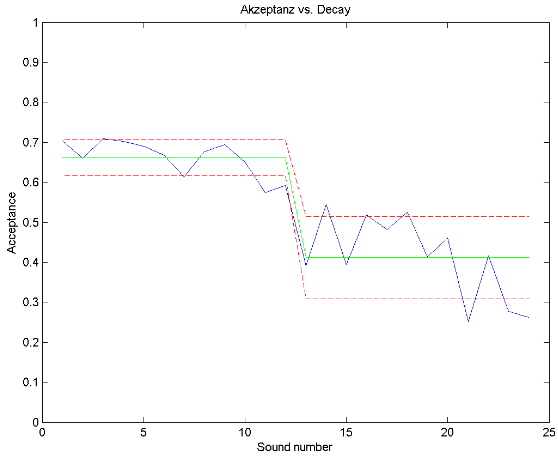

Figure 5: Sound numbers 1-12 use short decay time, sound numbers 13-24 the long setting. The green line denotes the average for each sound group, the red dashed line the standard deviation.

The according standard deviations of 0.05 and 0.1 respectively are the smallest values in the entire test. When all stimuli are taken into account, the attack time and the damping coefficient have no statistically meaningful effect. The shorter attack time is preferred marginally, the same is true for the higher damping coeficcient.

As for the specta, the effects are also within the standard deviation, however, the lowest-rated spectrum also shows the highest standard deviation in acceptance.

In a further analysis step the data of the sounds based on the slow decay time have been excluded (see Figure 6) to make the effect of the other parameters more obvious.

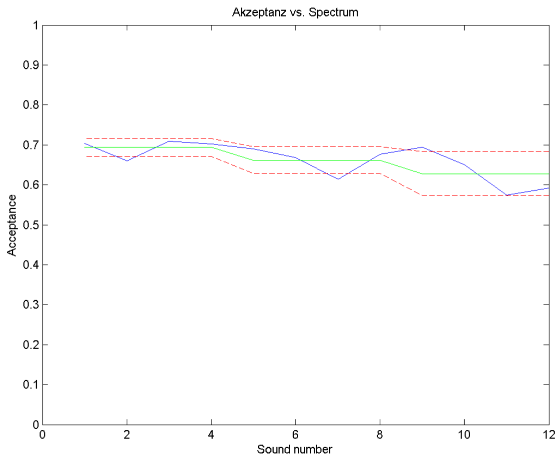

Figure 6: Sounds 1-4, 5-8 and 9-12 are based on the same spectra. Especially the sounds based on the third spectrum show a high standard deviation combined with a relatively low acceptacne.

Next Steps

Due to the strong effects of both decay time and peak amplitude, these two parameters will be examined more precisely in and adaptive 2-AFC test prodecure with the goal of establishing omptimum ranges from a perceptional point of view. The results gained from this test will be used for further studys regarding the spectral contents.

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