Experiences of using Shockwaves for Haptic Sensations

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Abstract

This paper reports on experiences using sound and air-based shockwaves for generating haptic-like sensations for groups of people in larger projection systems. Focusing on the generation of haptic feedback via alternative ways other than using ground- or body-referenced devices, several setups are described. An informal evaluation and a discussion of initial results are included.

1. Introduction

This paper focuses at the generation of haptic sensations other than using ground- or body-referenced devices that directly generate force on the user's body. The actuators used with such devices are usually focused at providing one user a close to reality haptic sensation by putting an actual force onto the person's body. What is considered the third kind of haptic device (see [3]), the tactile display, produces vibrotactile feedback which is in general less accurate than body and ground-coupled devices, but which could potentially be used to generate sensations for more than a single user.

During the setup of a new multi-speaker audio display it was envisioned to enrich the capabilities of this display system by generating haptic sensations for groups of people. Inspired by rock concerts and discotheques, an incentive idea was to use harmless shockwaves propelled at a user. The shockwaves that are looked into in this case study are sound and air-based. From several sources, background information can be obtained on how sound and airwaves can affect the human body. These sources are:

- Literature on the mechanisms of acoustics, specifically on *vibroacoustics*, being the field of research concerned with the vibrations caused by sound waves in the human body
- References to work performed on *acoustic weapons*
- Work performed on a*ir propulsion devices*

Sound-based shockwaves

Sound based shockwaves are predominantly researched in the fields of vibroacoustics and acoustic weapons. It is important to differentiate between *acoustic* ("hear") and *tactile* ("feel") components of sound waves. Sound waves can be sensed via [1][4]: transcutaneous sensing , bone structures (bone conduction), and via the cavities of the human body that pick up the sound frequencies. Sound waves can generate vibrations up to slight shocks in the human body.

Sound source	Frequency / intensity	Reported effects
Infrasound	Below 20Hz, high intensity (up to about 150dB)	Resonances in inner organs, vertigo, imbalance
Sonic Boom	2-20 Hz, extremely high intensity (up to 170dB peaks)	Resonances in body cavities, resonances in inner organs, extreme health issues
Acoustic pulse	Around 10Hz, focused beam, extremely high intensity	Possible knock out
General low frequency sound	Mainly 20Hz – 100Hz, up to 2.5 KHz, higher intensities (up to peaks of +/- 135dB)	Resonances in different body (air) cavities, resonances in inner organs

Vibrations caused by sound can be harmful, but can also have positive effects, which are experimented with for therapeutical purposes. Most of this work is concerned with lower-intensity sound waves. In order to generate haptic sensations using higher intensity sound waves, it is important to understand the effects of different frequencies and intensities on the human body. The table above provides a basic overview, based on [1]. Some frequencies cause resonances in the human body that can be felt as vibration-like sensation. The actual frequencies (ranging from about 2Hz to 2.5KHz) seem quite wide, even though indications can be found that especially frequencies below 100Hz can produce useable effects. The intensity of the sound wave needs to be tuned exactly – when the intensity will be above 130dB, health issues will become evident. Relating the information in the table to a general-purpose projection system setup, we need to be looking at intensities of between 85 and 100dB.

Air-based shockwaves

The basic idea behind air-based shock waves is to blow balls of air to a user. The devices to generate these balls are generally known under the name *vortex generator*. Using a box with flexible backside and a hole in the front, when the volume decreases by pulling and releasing the flexible backside, the pressure increases. Thereby it forces some of the air out of the hole. The velocity at which the air leaves the box is inversely proportional to the diameter of the hole; the smaller the hole the greater the velocity of the air. A good overview of vortex generators can be found at [2]. Many versions for children using rubber backsides are available, but the same effect can also be achieved by the membrane of a loudspeaker. The higher intensity air propulsion devices almost all make use of some kind of pneumatics. Just like wind, the air is sensed cutaneous by the movement of hairs on our skin. Extreme blows of air can result in slight deformation of the skin, thereby activating the transcutaneous sensing mechanisms.

Resulting from the searches through background literature and personal experiences, it was hypothesized that specific sound frequencies and intensities might generate a haptic sensation inside the user's body. In combination with air-based shockwaves this could lead to a way of providing both a somehow effective and entertaining (exciting) kind of haptic sensation for groups of users.

2. Related work

The work performed in this case study is directly related to research on haptic feedback. A good overview can be found in [3]. More specifically, research related to vibrotactile displays has played a source of inspiration. Some of these sources are [10][9]. The developed system described in the next section was inspired by the usage of vibrotactile elements in immersive displays to simulate earthquakes vibrations [5]. The concept of stimulating larger areas of the body has been tried in experimental systems like tactile vests using vibrotactile actuators or contractile shape-memory alloys [8], or the Aura Interactor. The latter device is basically a large loudspeaker mounted directly on the back of the user, vibrating heavily when activated.

The usage of alternative ways of providing haptic sensations has been greatly inspired by Yanagida's air cannon [11], which lead to the exploration of loudspeaker-based air cannons.

3. Setup

The particular case at hand was to install a new audio system in the iCone display environment at Fraunhofer IMK. The iCone is a spherical visual display of about 7 meters diameter and a 210 degrees field of view, with slightly tilted walls (7 degrees to the back), giving it a conical form. One of the advantages of the conical form is reduction of acoustic reflections, making it better for sound display than normal spherical display systems. The previously used 9-speaker system was to be replaced by a system that would support full surround sound. Therefore, 16 new speakers were acquired, that where to be placed in a spherical setup, in a top and bottom ring. Previous listening tests concluded that the lower end of the sounds spectrum needed some support from a subwoofer. In combination with the incentive to use subwoofers to generate haptic experiences in the center of the display system, the first prototypical system, called the SoundMaster 2000, was made. It was built of three massive 17" (43 cm) low frequency speakers built in a triangular MDF casing, placed in the centre of the iCone. First experiments showed that low frequencies produced an acceptable range of sounds that could be combined with the normal speakers for normal sound production. A wide range of sound frequencies was produced to test the effects of lower up to subsonic frequencies on the human body. Though, it only produced minimal haptics through vibration of the floor and only very little haptic sensations by having an effect on other body parts than human feet. Assuming that the volume of the speaker casing was too small, a tile of the double floor was taken out, whereby the speaker was placed over the opening, thereby enlarging the resonance volume considerably by taking effect of the large double floor space. Nevertheless, the loudspeaker did not produce the wanted haptic effects, next to the fact that the construction was occupying too much space in the display system.

The next step was to take the large subwoofer apart, making multiple subwoofers to be placed outside of the iCone display. Hereby, 4 loudspeakers where built with a size of about 18" x 18" x 18". The volume of the box is about 125 liters which for a closed box results in a resonant frequency of approximately 56 Hz. Holes where made in floor tiles so that two of the subwoofers, placed just outside the iCone in the left and right corner, could exactly fit with the speaker (membrane) into the floor. The floor in the iCone is a double-layered floor with a total volume of about 1850 liters between tiles and concrete floor, where the resonant frequency would be around 31 Hz. A second pair of speakers was placed behind the iCone, taking advantage of the reflection of the back corner for producing low frequency sounds. When placing loudspeakers in a corner the lower frequencies radiating in a circular pattern are reflected by the walls and sum up with the unreflected sound waves.

Using sound samples and music files, the loudspeakers where calibrated first to produce a balanced audio spectrum with the normal speakers. In a second step, it was tried to generate sound-based shockwaves. Hereby, the loudspeakers proved highly effective to produce the lower basses – basically, using higher volumes, the whole part of the building was slightly vibrating. Due to the large double floor space used as extra resonance volume, all rooms that are at the same level, and below (cellar) the double floor noticed considerable lower frequencies, up to vibrations. Nevertheless, the shocks were mainly floor vibrations. Additionally, the audio waves did not have a maximum in the centre of the iCone (the hotspot were most users will be immersed), since the vibrations where felt most strongly at the border and outside the display system.

Hence, the sound waves had to be adapted in order to produce the necessary results in the middle of the iCone - the subwoofers standing in the left and right corner where delayed for about 7ms, to create a maximum for frequencies around 30 Hz in the centre of the iCone, resulting in vibrations and a clear experience of lower frequency sounds (related to the sound samples) in the hotspot of the display system. Tests were run, whereby low frequencies were generated around 95-100dB. Hereby, in the software the sound spectrum was adapted to produce more lower frequencies by applying separate filtering on the subwoofer channels. Nevertheless, this adaptation would not disrupt the generation of sound for other applications using the display systems.

Even though the lower frequencies could be sensed in the body, mainly through floor vibration, its effects were unsatisfactory – it generally produced a deep “bass sound”. Since higher levels (above 100dB) would generate too much vibration inside the building and could decalibrate the display hardware (projectors), the idea of audio shockwaves by using subwoofers was aborted.

Following up the previous success by colleagues with vibration elements for simulating earthquake vibrations, a next step was to install a large area vibrotactile area in the iCone. Because the height of the floor is limited it was not possible to construct a vibration floor without keeping the centre of the iCone leveled with the rest of the room. In the centre of the iCone, five floor tiles were mounted with Paraseats (25W “tactile transducers” exclusively producing low frequencies). Paraseats are extremely effective for producing vibrations and small shocks. The vibrations were in sync with lower frequencies generated by the subwoofers, thereby producing a nice experience of “bass sounds”. The Paraseat drivers are driven through a separate audio channel in the software, so special effects like rumble or other vibrations can be directed by the application. A similar setup was in use in the CAVE at the Fraunhofer IMK-VE group. The original AVANGO Cyberstage Soundserver has the capability of using a separate channel for driving vibrations elements [6].

Air cannon prototype

Leaving the trail of sound-based shockwaves, experiments were started using air-based methods. Inspired by different vortex generators, several designs were analyzed. Encouraged by designs using loudspeakers mounted in a cylindrical volume, a small air cannon was produced. The air cannon was made of a 10” mid and low frequency speaker, mounted in a recycle bin. On top, a round wooden plate was glued, with an opening through which a small plastic pipe (about 2” diameter and 11” length) was put. Testing the device, it unfortunately only produced slightly noticeable air balls up to a distance of about 2 feet.

4. Informal evaluation

The setup and usage of the different developed components has been probed over a period of over two years. Personal observation and experience of audio experts, direct and indirect feedback (observations) from several hundreds of users experiencing demonstrations inside the display system, and acoustic measurements have resulted in the following results.

From its first setup on, the acoustic quality of the system was never an issue. Users especially report on the effects of the sound floor – acoustic effects like a heartbeat in a medical demo can be clearly experienced via vibration. Most users do not directly realize the haptic effects of the system, but just seem to enjoy the tactile characteristics of the sound display. Hereby, the user's body is clearly shocked by the vibrations of the floor with soft but clear sensations in stomach and chest, generated by both the subwoofers and the Paraseats. Thus, most tactile/haptic effects seem to be generated by conduction of vibration from the feet through the bone structure of the user. By using separate channels for low frequency reproduction, it is possible to tune the maximum for certain locations in the room, however these locations are only valid for certain frequencies. The central area of the iCone is tuned for frequencies between 30 and 60 Hz. Using a single subwoofer, this kind of effect would be difficult to realize.

The "blast effects" could not be fully repeated inside the display system. We could increase the sound level to such a point that the full building (including users) was vibrating, but in general usage, this is not acceptable. We cannot report on any negative side effects of using the system, till current date. ISO 2631 [7] reports that vibrations from 1 up to 80Hz can result into health issues like drowsiness or stomach problems. Nonetheless, no user of the system reported on such issues. The construction of the air cannon was basically evaluated negatively. Since it only produces slightly noticeable pops of air within a distance of up to maximum 2 feet, it was unusable in the display system. A newer version of the system is under design, but could not be tested till current date.

5. Conclusion

The setup of the different devices has been a trial-and-error process. Starting with the subwoofers, we were able to produce an incredible amount of lower frequencies for the size of space of the display system. Using the subwoofers and sub floor space together with the Paraseats is a good way of generating deep basses and vibrations. Users clearly notice shocks coming through the feet, being conducted by the bone structure throughout the body, into the stomach and the chest. To these vibrations, the user does not connect any specific direction (directional cue). Therefore, in interfaces, the vibrations could only be used for general purposes. The validity of the vibrations therefore mainly seems to be to enhance a sound system by making sound effects tactile, possibly in a larger spatial area. The tactility can be well applied for simulating the effects of collisions, like running into a wall. Additionally, the vibration seems to provide motion cues. The most plausible explanation for this effect is that a part of the inner ear is sensitive to vibrations above a certain level (90dB) and generates motion sensations.

The first attempts of coupling audio and air-based shockwaves were futile. Nevertheless, the concept seems realizable – enough devices can be found that effectively propel air to user. The problem with most devices is its size, and the need for automatisation. A pneumatic air cannon using multiple nozzles, mounted under floor tiles is conceptualized, but could not be built till now.

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References

[1] Altmann, J. (2001). "Acoustic Weapons - A Prospective Assessment." Science & Global Security **9**: 165-234.
[2] Beaty, B. Ring Vortex (smoke ring) Launchers, available at: http://www.amasci.com/amateur/vortgen.html.
[3] Burdea, G. C. (1994). Force and Touch Feedback for Virtual Reality, Wiley Interscience.
[4] Cook, J., D. Fiely, et al. (1995). "Nonlethal Weapons, Technologies, Legalities, and Potential Policies." Airpower Journal Special Edition 1995.
[5] Dombois, F. (2002). Using Audification in Planetary Seismology. 7th International Conference on Auditory Display, Espoo, Finland.
[6] Eckel, G. (1999). Applications of the Cyberstage Spatial Sound Server. Audio Engineering Society 16th International Conference on Spatial Sound Reproduction.
[7] ISO (2003). ISO Standard 2631 - Whole-body vibration, available at: http://www.iso.org/iso/en/CatalogueListPage.CatalogueList?ICS1=13&ICS2=160&ICS3=&scopelist=.
[8] Jones, L., M. Nakamura, et al. (2004). Development of a Tactile Vest. HAPTICS'04, Chicago, USA.
[9] Okamura, A., J. Dennerlein, et al. (1998). Vibration feedback models for virtual environments. IEEE International conference on Robotics and Automation, Leuven, Belgium.
[10] Tan, H. and A. Pentland (1997). Tactual displays for wearable computing. IEEE ISWC.
[11] Yanagida, Y., S. Kawato, et al. (2003). A Nose-tracked, Personal Olfactory Display. ACM Siggraph 2003.