ACTIVE SOUND DESIGN: VACUUM CLEANER

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ABSTRACT

The acoustical channel is explicitly feasible to intuitively inform the user of a product about the current status of operation and to give a feedback about the performed action. The inherently produced sound of the product often is not sufficient to give an appropriate feedback, so that additional signals have to be generated and reproduced. A patent pending method of Active Sound Design for vacuum cleaners is presented in this paper. The amount of currently aspired dust is measured, and this data is used to generate an acoustical feedback. This feedback is played back via a loudspeaker integrated into the vacuum cleaner.

INTRODUCTION

The definition of Sound Quality by Blauert and Bodden (1994, "Sound Quality is the suitability of a sound for a specific technical task", see also Bodden, 1997) means that the sounds of products are not undesired in general, but that they fulfill a specific purpose. In this context the aspects of interaction in order to be able to control and to handle a product and the satisfaction of the user are especially important. The sounds that products emit are not only noises, they are suitable to transmit information to the user. The acoustical channel is especially suitable to inform the user about the status of operation of a product and to give a feedback about the executed action. The advantage of this acoustical feedback compared to feedback in other modalities (optical, tactile, etc) is that this information is transmitted in an intuitive and unmistakable manner without blocking the attention of the user and without requiring big efforts.

In general product sounds are inherently produced by the mechanical function of a product. This dependency has two principal disadvantages – it first limits the possibilities of Sound Design, and second it usually results in high costs for a sound optimisation since this optimisation has to be implemented by changes of the sound origin and thus by changes of the mechanical function. In contrast to that in Active Sound Design additional sounds are generated and superimposed with the inherently produced sound, which allows for an extended freedom of Sound Design and a higher sound variability, and often also results in cost reductions.

It also has to be considered that in some cases the inherently produced feedback is not sufficient or not suitable for the task to be performed with the product. This is for example the case for vacuum cleaners: this type of product usually produces noise of a relatively high level so that it disturbs and annoys the user, but it does not give him any suitable information about its status of operation and the performed task. The possibilities of Active Sound Design will be discussed using the example of the vacuum cleaner in this paper.

ACTIVE SOUND DESIGN

Active Sound Design means that in addition to the inherently produced sound of a product sounds which give useful information to the user are “actively” generated and reproduced. The motivation for Active Sound Design is based on three main circumstances: by the change of functional principles of products, by missing or unsuitable feedback, and by cost reasons.

In the past products were mainly based on mechanical functions which automatically created typical noises when the product was operated. These type of noises offer the disadvantage that their level and their Sound Quality often is difficult to control and optimise. As a consequence of the change of more and more mechanical processes into electronic circuits also the corresponding sounds disappear or change. An example is the direction indicator of vehicles, a sound which was dominated by the characteristic “click” of the mechanical function of the relay. If the relay is replaced by a pure electronic circuit, also the characteristic sound disappears. But, drivers were used to this typical sound for several decades, and this sound was unmistakably interpreted as a feedback that the direction indicator was turned on. Active methods here mostly just reproduce the sound of the former relay click and do not use possibilities of Sound Design, but they meet the requirements of the user – he is used to this sound and in most cases he does not even realize that some functional principals had been changed and that the relay might no longer be included.

In contrast to that example where a former mechanical sound is more or less directly reproduced by an active method, Active Sound Design in principal offers an extraordinary amount of freedom of design. Since sounds can be generated without the direct link to the mechanical operation in principal any type of sound can be designed. This gives the sound designer a lot of freedom, but he has to take care that the product and user specific requirements are met if the Active Sound Design should be successful. The requirements are:

- the feedback has to meet the expectations and requirements of the user;
- the feedback has to be meaningful, unmistakable, and intuitive;
- the sound has to fit to the original product sound and has to be perceived in it;
- cost and realization aspects have to be considered;

A typical implementation of Active Sound Design for vacuum cleaners will be presented on the following.

VACUUM CLEANER

The sounds of vacuum cleaners are usually of high level and mostly are perceived as being annoying and disturbing. Furthermore, the sound does not give any useful information to the user besides that the cleaner is switched on and eventually at which power setting it is working. Especially any type of feedback concerning the original task and function of the cleaner is missing, namely about the aspiration of dust. The fine dust particles which should be aspired by the cleaner are not visible to the user, so that he has to use his intuition and use the cleaner until he thinks that the floor is cleaned.

For this reason an Active Sound Design was developed in order to give the user the required information about the current operation and the progress of cleaning. Fig. 1 shows the scheme of the resulting method.

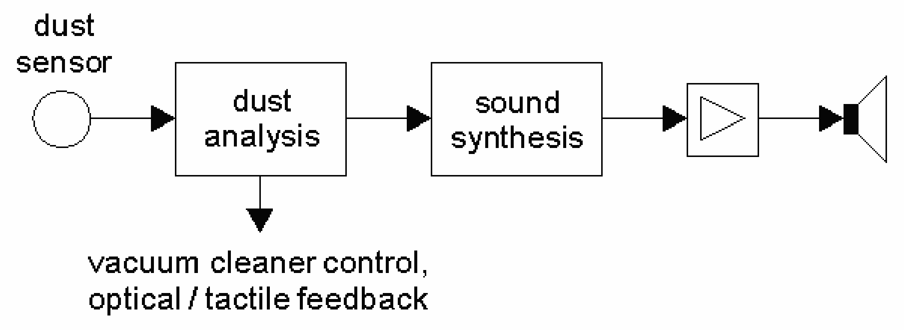

Fig. 1: Scheme of the Active Sound Design for vacuum cleaners

A sensor measures the amount of the actually aspired particles, an acoustical signal is generated from that information, and this signal is reproduced via a loudspeaker integrated into the vacuum cleaner.

Dust Measurement

If a feedback about the actual operation and the progress of cleaning should be given, first information about these parameters have to be recorded. In the method presented here a specific dust sensor is used which directly measures and analyses the amount of particles which are actually aspired by the cleaner.

This sensor (patent E 0 759 157 B1) has to be placed in such a way that particles hit it. The underlying process is that particles hitting the sensor create waves on its surface. Due to the piezoelectric mechanism these mechanical waves are transformed into electronic waves, and the amplitude, time and frequency composition of these waves allows to identify specific characteristics of the particles.

For the vacuum cleaner the sensor has to be placed in the flow stream, e.g., into a bend of the pipe. The output signal of the sensor thus contains information about the amount of particles hitting it, their weight, speed, and type of material.

The sensor signal is fed into an analysis unit which determines the necessary information about the aspired dust. Under the assumption that the speed of the particles is constant besides the number of particles also their weight can be determined. In doing so, continuous information about the dust flow is made available. If this dust flow is traced over time, the progress of the operation is quantified, and it also is measure for the degree of cleanness of the floor.

In the application presented here the signal from the dust analysis unit is used to create an acoustical feedback. But, it could also be used to control the vacuum cleaner itself, e.g., to automatically adjust the power to the amount of aspired dust. In addition it can of course also be used to give a feedback in a different modality, e.g., in optical or tactile form. Nevertheless, the acoustical feedback is more practicable for the user and more sophisticated here.

Acoustical Feedback

Active Sound Design offer the possibility to generate arbitrary types of sounds. However, the requirements listed above limit the possibilities substantially for the application presented here. The biggest restriction represents the basic sound of the vacuum cleaner itself, which usually is loud and annoying. The feedback has to be heard in this signal and has to fit to it, so that a lot of sounds can not be used. Any type of musical and harmonic sound for example is not suitable. They might sound good and appropriate without the background noise, but the background noise will disturb their perception and result in additional annoyance and stress of the user.

A further limitation is the necessity to reproduce the sound with the required loudness and sound quality but for marginal costs. Low cost speakers usually are only capable to reproduce a limited frequency and loudness range without too big distortions.

Feedback signals which exist today often belong more to the class of warning signals. These signals are just played at specific events indicating specific actions (e.g., the signal of a microwave oven, or sounds of a computer). Usually these signals do not have a direct link to the action which the product is performing or to the message to be displayed, so that the user has to adapt to them and has to learn the relation between the acoustical feedback and its meaning (see also Dürrer and Jekosch, 2000).

In contrast to that for the application of the vacuum cleaner presented here the intention was to design a sound which can intuitively be interpreted without any further learning phase of the user. This sound thus has to be a sound which the user of a vacuum cleaner knows and which he automatically understands as a “cleaning“ sound. Such a typical sound occurs if – compared to fine dust - bigger particles like sand are aspired. The bouncing of the particles in the tube produces characteristic clicks, and if multiple particles are aspired a characteristic “drumming” can be heard.

If normal or fine dust particles are aspired this characteristic sound is not produced because the particles are too small and have not enough weight. The Active Sound Design now produces the missing sound, and as a result the dust particles are acoustically transformed to bigger particles.

The sound generation does not perform a complete synthesis, it uses original sound samples as a basis. It is performed as follows:

- the basic samples consist of sounds of three different particles. The sound were produced by letting them drop on a surface, and digitally recorded and stored. The materials and weights of the particles and the surface were varied, they determine the character of the sound;

- the signal of the dust analysis controls the generation of the output signal;

- the actual sample is selected based on the weight of the aspired particle. Three ranges of weights are defined, and each range is associated with a respective sample;

- the playback amplitude is directly linked to the weight of the particle;

- the occurrence frequency is calculated from the number of aspired particles. In principal each aspired particle could be represented by a reproduced sample, but since the sensor also detects fine dust, this would result in too many sounds. The occurrence frequency thus is a fraction of the dust particle rate;

- the determined playback amplitude and occurrence rate are superimposed by a random function in order to create a signal without periodic structure and with sufficient variability;

- the samples are concatenated accordingly and are fed to the playback unit.

The amount of three particles has proven to be adequate to create a sufficiently diversified sound. The aspired amount of dust is represented in form of the occurrence frequency and the amplitude of the samples, which also avoids a monotony of the sound. The samples itself are optimized with respect to the necessary length, the sample rate and the resolution resulting in a storage requirement of only 768 Byte per sample.

The resulting signals sound very similar to the known sound of aspired bigger particles.

Reproduction

Active Sound Design requires a possibility to reproduce sounds. In general products to not offer devices for this purpose, so that they have to be implemented. Exceptions are applications for the vehicle interiors, were the existing loudspeakers and amplifiers might be used.

The requirements to the playback device are defined by the type of acoustical feedback created and the background noise inherently produced by the product. For the application presented here the sounds have been designed in such a manner that a simple, small and cost efficient reproduction system can be implemented. The feedback sounds consists of a concatenation of mainly clicks which do not contain specific harmonic or tonal structures, and distortions of loudspeakers are not so important here.

The resulting speaker consists of a small piezo element with a special housing an is depicted in Fig. 2.

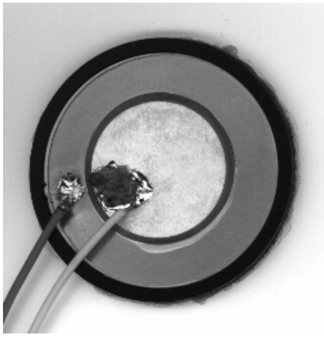

Fig. 2: Piezo element used as a loudspeaker

The piezo element placed in such a manner in the vacuum cleaner that it profits from the coupling to the cleaner housing. Parts of the cleaner housing surface are thus practically used as loudspeaker, and the included air volume serves as a resonator. The resulting playback system is able to reproduce the acoustical feedback with a sufficient loudness and sound quality in the vacuum cleaner background noise.

In principle the reproduction system for Active Sound Design could also utilize other channels, e.g., headphones (i.e., also with integrated active noise reduction to reduce the influence of the inherently produced product noise or other types of background noise in the environment) or transmission to external existing playback systems. A reproduction via headphones offers the advantage that the influence of the original product sound is reduced, so that the degree of freedom for the design of the acoustical feedback is higher.

Usage Of The Vacuum Cleaner

A vacuum cleaner normally is used in such a manner that the cleaner is moved several times over the same surface segment. In doing so, the amount of aspired particles is continuously decreasing since the surface is more and more cleaned. Without any feedback the decision to move to another segment is not based on the achieved cleanness of the floor, but purely on intuition of the user. The Active Sound Design presents this missing information to the user, resulting in the following advantages:

- the user gets a feedback which facilitates the handling of the product and which enhances the performance of his task;
- the acoustical feedback is subconsciously processed and thus does not block or divert the attention of the user as it would be the case for example for an optical feedback;

- the acoustical feedback is self-explanatory and unmistakable;
- the positive feedback about the process and progress of cleaning “rewards” the user and increases his motivation. He gets the feedback that his work is worth doing and that he does a good job, since the dust flow is continuously decreasing;
- the image of the product is increased.

The resulting acoustical feedback thus is an effective means to increase the product quality, and shows advantages compared to, e.g., an optical feedback. In addition, a degree of required cleanness can be preset using this technique, so that an appropriate feedback can be given once that this degree is achieved. This would allow to include a quality control for the professional cleaning sector.

SUMMARY

Active Sound Design is a new, effective, and often also cost efficient method to equip a product with a suitable acoustical feedback. Since the generation of the sound is no longer coupled to the functional mechanisms of the product, nearly unlimited possibilities for the sound design are offered. In case of a careful and responsible design the handling of products and the satisfaction of clients can substantially be enhanced - as well as the quality of the product.

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