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PRODUCT SOUND DESIGN IN EDUCATION

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ABSTRACT
Product Sound Design is an elective course of the Master of Industrial Design Engineering at the Delft University of Technology. The educational goal of the course is to make students consciously aware of constructive parts in the design of appliances. The paper details the experience and the design of product sounds. The course runs during the second half year and the students are involved through project teams.
Products have mostly moving parts with a certain mass that generate sounds. Clearance is the result of tolerances of two fitted parts and the quality of manufacturing these parts. Two types of sounds can be distinguished: intentional sounds and consequential sounds. In product sound design an integrative vision of perception and engineering is needed to be a successful designer/engineer of products.
The content of the product sound design course has three main subjects to explain: product, product sound and product sound design. The first quarter consists of an intentional sound project and the consequential sound project takes place in the second quarter. The education format is two projects, one in each quarter, and supported by lectures. The project is finished with a presentation and report. Results for projects in the academic year 2010-2011 will be presented. Findings of these projects will be adapted in the next course. The experiences of course leaders and students are good, which is translated in relatively good marks. The product sound design course fills the gap that exists between sound experts and product designers.

Keywords: Product sound design, sound, product, education

1 INTRODUCTION

In our daily life we experience various sounds throughout the day, such as traffic sounds, musical sounds, nature sounds, and product sounds. Within the domain of product sounds, a distinction can be made between intentional product sounds and consequential product sounds [1]. Intentional product sounds, such as a petrol level indicator in a car, is designed on purpose, and is often implemented by means of a loudspeaker. On the other hand, consequential product sounds, like the buzzing of an electrical shaver, are sounds resulting from mechanical interactions between product parts. As these sounds influence our behaviour during the day, it is important for product designers to consider sound as part of the design process [2]. However, there is a lack of knowledge on the relation between auditory product properties (e.g., loudness, roughness), mechanical product properties (e.g., transmission), and product properties resulting from the manufacturing process (e.g., tolerance). For this reason, a shared knowledge based on the experience with a large number of product sounds should be built up.
The course Product Sound Design (PSD) is an elective course in the master program of Industrial Design Engineering at the Delft University of Technology. The course is taught in the second half of the academic year, of which the third quarter focuses on intentional product sounds, and the fourth quarter on consequential product sounds. In the third quarter five lectures are given on sound perception, redesign and the interactions users have with products. Besides these lectures, teams of two students carry out an intentional sounds project regarding a daily life interaction situation. The project teams should accurately record the sound, and analyze the perception and experience of the interaction. This knowledge will be used for (re)designing a new sound. In the fourth quarter three lectures are given on consequential sounds, and on radiation and transport of sound. Additionally, the student teams carry out a consequential sound project on a consumer product used in daily life. The teams make repeated sound recordings of the product in different stages of deconstruction. This way,

the contribution of separate parts could be established. The recording process requires an anechoic chamber, which is available in the sound laboratory of the faculty. The deliverable of the project is an analysis of the product, and suggestions for a redesign. The redesign may consist of suggestions for new parts and principles, as well as suggestions for sound damping and isolation. Students should demonstrate knowledge about the sound source, as well as radiation and transport of sound.
This paper starts with a general overview of fundamental concepts in Product Sound Design, and describes the results of two projects of the PSD course.

2 CONTENTS OF THE PRODUCT SOUND DESIGN COURSE

As the PSD course involves students with a background in engineering, business, or design, three main subjects are explained in order to understand the nature of the product sound design projects.

2.1 Products

A product is the result of a design process that starts with a design problem, involves ideation phases, and ultimately leads to a market introduction. In the context of the PSD course mainly domestic appliances are considered. Working principles are often based on the energy conversion. Therefore, these products are usually powered by the electric grid, or with a battery. The most convenient energy is electricity, but electricity can also be converted to heat for heating and cooking, and to rotational energy by means of an electrical motor. Moving parts can be driven either directly, or with a transmission system. Each product part potentially has six degrees of freedom. Three of them are transversal, and the other three are rotational. For example, a gear shaft has only one degree of freedom, namely rotation around its own axis. All the other degrees of freedom should be restricted to zero by the construction. For this purpose, fixed, detachable, and combination joints are available [3]. Tolerances are the result of the chosen manufacturing process, which is determined by the material, shape, size and volume of production. Moving parts need a certain clearance to realise their relative movements [4]. A minimum and a maximum clearance can be determined depending on the tolerances of two parts, as well as small expansions due to temperature increases.

2.2 Product Sounds

When a physical sound has a certain sound pressure level at a certain frequency, we perceive it through our auditory system with a certain loudness and pitch. The human ear without hearing loss is susceptible to sounds within a frequency range of about 20 Hz to 20.000 Hz. Infrasound (i.e., sound with frequencies below 20 Hz) is not important for air borne sound, but can be relevant to consider for structure vibrations [5]. Ultrasound (i.e., sounds above the audible frequency range) is used in technical applications, such as acoustic modelling techniques, medical diagnosis, non-destructive material testing, and ultrasonic welding. The focus of the PSD course is on audible product sounds. Six product sound categories have been identified from an experiential perspective [6]: alarm (e.g., digital alarm clock, microwave beep), air (hairdryer), mechanical (electric shaver), cyclic (tumble dryer), liquid (coffee machine), and impact (keyboard buttons). Sounds of the first category are generally implemented by means of a speaker, and can be considered as intentional sounds. The other product sound categories are consequential product sounds.
From a sound engineering perspective, the basic elements to consider are sound source, sound medium, transmission, radiation, emission, absorption, damping and isolation. All of these elements have an influence on the physical properties of sounds, and how these sounds manifest themselves in an environment: wave type, wave length, frequency, propagation speed, intensity, sound pressure, impedance, and sound power [7].
A joint is a connection between two or more parts. Joints can be fixed, freely moveable, or controlled moveable. Controlled moveable typically means that movement is only possible in one direction (e.g., a gear shaft rotating around its own axis). The clearance between the parts allows for movements of mass, which initiate sound pressure waves that the user of a product may experience as sound. Therefore, the clearance between two parts is a predictor of sound emitted by product parts. Sound transmission takes place through a variety of engineering elements [8]. However, air and fluid borne sounds take place through air and fluid-filled cavities and channels. Sound radiation arises from vibrating surfaces and/or moving mechanical parts. When a sound wave propagates from one medium to another, the acoustical impedance of the medium determines whether the sound wave is completely absorbed, or whether sound radiation takes place [9].

The isolation is to reduce sound by means of reflection [10]. The reflected sound wave is the difference among the invading sound wave and the transmitted sound wave, so the sound reduction is strongly dependent on the material property that is expressed with the impedance. The impedance is the specific gravity multiplied by the corresponding speed. By the masses to be spring on the reflection will also considerably reduced, which is called sound insulation construction.

Absorption is to reduce the sound transmission through dissipation, but it is named damping for structure-borne sound. The dissipation of the sound energy is transformed into heat. In air cavities sound-absorbing materials are used, which are usually placed between faces or glued on plates.

Product sound designers should know about the auditory impact of manipulations of these basic engineering elements.

2.3 Product Sound Design Process

When designing or engineering product sounds, one should take into account the role of user experience and context. For example, an alarm sound should loud enough to be audible in a possibly noisy environment, and in the context of an intensive care unit the alarm sound should be perceived as, e.g., urgent. Therefore, the product sound designer should know about the interactions users have with products in a context. However, they should also know how product layout, stiffness, and moving masses influence and/or initiate sounds. On top of that, they should know how the manufacturing process (i.e., assembly accuracy and parts manufacturing accuracy) affects these physical product properties, and consequentially the product sound quality [11]. Unfortunately existing design rules for domestic appliances do not provide an insight into the type of product sounds that may emerge from a particular design solution. Therefore, students of the PSD course will learn from hands-on experience with product sound design problems.

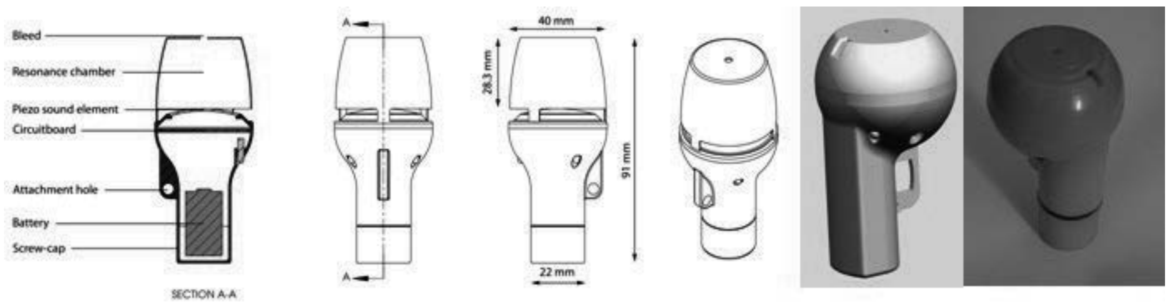
Students perform two projects: one on intentional sounds and one on consequential sounds. The process used in these projects is similar to the design process, consisting of an analysis, conceptualization, embodiment, and realization phase. Analyses of sound requirements define the conditions for the conceptualization phase. Multiple concepts are developed, of which one is chosen for further development in the embodiment phase. In the realization phase a prototype is made, and tested under the most reliable condition. Nevertheless, students are given the freedom to choose a different process if they think it is appropriate.

In the intentional sound project students have to explore human-product interactions in a given context (e.g., a train platform), to design or redesign an appropriate sound for an existing product (e.g., a check-in device). Audiovisual recordings (i.e., using a video recorder and an audio field recorder) are suggested as medium to analyze interactions in a context, as they provide an overview of the interactions themselves, as well as which other product and environmental sounds are present. Analysis of existing interactions and sounds is a starting point of the conceptualization phase, but in order to develop concepts it is essential to first develop a sound design vision. Mood boards can be helpful to identify a sound quality that is appropriate for both the end-user of the product, and for other people in the same area. Knowledge mapping [12] is a helpful technique to get a grip on which acoustical parameters may result in the desired sound quality. Designing a new sound within the constructed vision requires a substantial creative effort from the students. To evaluate whether the designed sound complies with the vision and whether it is appropriate in the given context, it should be tested in a realistic situation. In case this is not attainable, a mock-up may be built to enact the interaction. Background sounds can be used to put the designed sound in an auditory context.

In the consequential sound project students redesign the sound of a domestic appliance, this is sponsored by an interested company or bought for the course. Consequential product sounds may be designed in the conceptual design phase, but the elements that lead to these sounds (i.e., tolerances, surface roughness, assembly accuracy) are often not considered during the early phases of the design process. Design experience is needed to predict the implication of these elements on the emerging sound. The principles of Design for Assembly [13] may help to gain an initial understanding of these relations during the analysis phase. The contribution to the total sound of each product part, component, or sub-assembly can be established by comparing sound recordings of the appliance in different stages of disassembling. In that case, disassembly should take place until the electro motor is the last part that remains. Static products (i.e., without moving parts) are unlikely to emit sound in the form of radiation, but may transmit or emit sound upon impact. In some cases it is not possible to disassemble a product while keeping its working principle intact. In other cases the presence of electric wires may lead to potentially dangerous situations. Cutting a hole in the shell may solve these problems. Halfway through the project the students have to hand in a measuring plan to check the feasibility of their approach. The step by step disassembly approach should be documented by the students in order to make progress in the project. Complemented with an analysis of the interaction with the product, students will formulate a tentative vision on improvements of the product's sound quality. Improvements may be designed as new parts, or modifications to existing parts. The redesign or modification should be built as a testable prototype, to evaluate whether improvements have been made.

3 EDUCATION

The chosen education format for the PSD course is a combination of lectures and projects, in which the lectures support the projects. For the intentional sound project knowledge is provided on sound perception, design principles, and on formulating a vision. The student teams complete the projects with a hardcopy report and an oral presentation with auditory and visual information. For the consequential sound project the lectures are tailored towards relations between mechanical and auditory product properties. Halfway through the project the teams have to discuss a measuring plan with the course leaders, in which they also have to predict how they expect to measure the results of a redesign or modifications of the product. As a redesign requires more effort than a modification, this often results in a higher grade. The students only have fixed contact moments at the start of the projects, and at the presentations of the projects. In case of questions, additional contact moments can be scheduled on demand. The workload is 168 hours for 6 ECTS credits, which means that compulsory attendance is demanded only 15% of their study time. The product sound design course has been run twice with great satisfaction of both the course leaders and the students.
The course was taught for the first time in the academic year 2009-2010. The nautical Kid Siren water alarm was used as product for the intentional sound project. This is an alarm that is detachable from a



a b c

Figure 1 a. redesign, b. computer model, c. original product

life vest, which is triggered when it makes contact with water. The student teams revealed with their interaction analysis that a child may enter the water in unknown manners. As the top part of the Kid Siren was able to hit the water, it was found that water could enter the housing and dampen the sound pressure level. Based on a mind mapping exercise, each team chose a feature to focus on for the warning sound. Knowledge on sound perception (e.g., loudness and masking effects due to context) helped the students to identify boundaries of their solution space. Two teams showed a redesign of the Kid Siren. Afterwards the prototypes were printed and tested (see figure 1). The problem of dampening the sound pressure level by water was not solved, because the point of gravity was changed. As a result, the alarm would turn on its side and still make water. However, the learning experience for students was how to create a warning sound that makes people alert on saving a child from death by drowning. Due to practical reasons it was not possible to test and evaluate the designed sound and redesign.
The consequential sound project consisted of a selection of electric toothbrushes of different brands. The goal of the project was to learn about the origins of these product sounds, and to propose an appropriate redesign or modification. The student teams prepared a measuring plan, and discussed their setup and proposed solution with the course leaders. The head of the toothbrush was

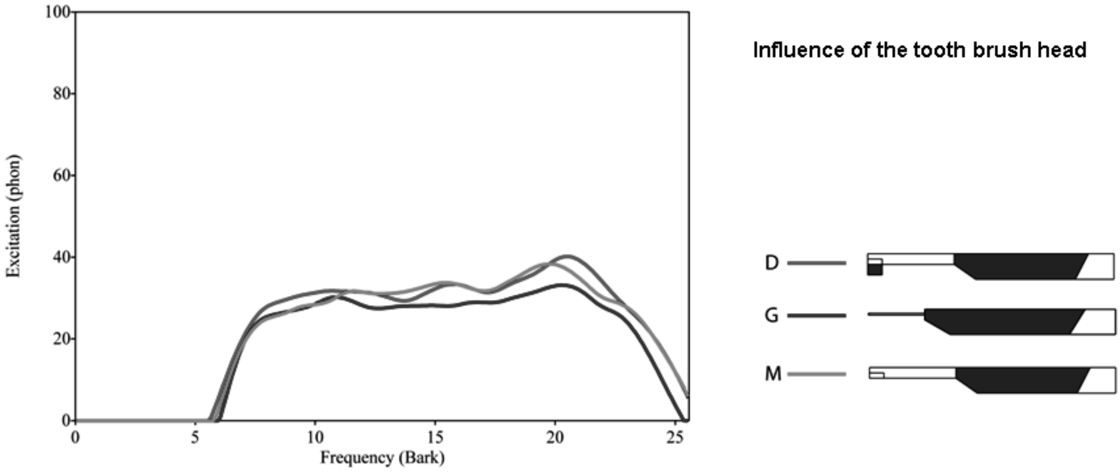


Figure 2. Bark representation of the tooth brush head in different stadium

disassembled and recorded step by step. In Fig. 2 the perceived loudness of these recordings is expressed as function of the frequency. The figure shows that the situation without the toothbrush head is the quietest. Adding the head holder increases the loudness, and the loudest situation is found with the complete head attached. Further analyses showed that for many toothbrushes the drive of the toothbrush had the biggest impact on the sound. This suggests that sound improvements are best made by changing or adjusting the working principle. Some student teams chose to isolate the sound, whereas other teams chose to use other materials. Lowering of the clearance of the parts could have been an improvement as well, but this was not considered by the students.

In the academic year 2010-2011 the intentional sound project of the PSD course dealt with the sounds of the Dutch public transport card. This card can be held in front of a scanner to check-in and check-out when going by train, tram, metro, and bus. Both actions are currently confirmed through messages on a small display and two different auditory signals (i.e., ‘beep’ for check-in and ‘beep-beep’ for check-out). An error signal is heard in case something went wrong (e.g., when there’s no credit left). The student teams discovered a number of shortcomings in the sound when interacting with the card and scanner. For example, it was hard to understand the different meanings of the check-in and check-out signals, and identification of the signals was hindered when two opposing scanners were used simultaneously. Furthermore, in some lighting conditions the brightness of the visual feedback was too low for people wearing glasses, which necessitates a proper sound design.

A collection of mini choppers of different brands was used for the consequential sound project. These mini choppers are mainly used in the kitchen to process food. Some mini choppers were single speed, whereas others had multiple speed options. There were two main learning experiences. First, the steel pin insert that holds the rotating knives of the bowl was found to initiate a rattling sound. The pin was not centred on the axis of the knives, which could be retraced to manufacturing accuracy of product parts. Second, students learned that introducing more moving parts (e.g., gears) potentially leads to more sound, even though the function of the appliance remains the same. One student team tackled this problem by filling cavities around the gears with sound absorbing material, so less sound could be radiated and transmitted. These findings are implemented in the upcoming lectures in the fourth quarter of the next academic year.

4 DISCUSSION

Our main finding was that students learn more concerning constructive aspects of products when they need to relate these aspects to auditory perceptual features. Moreover, because of sound results from the integration of individual constructive aspects, students get more focused on how specific parts relate to the holistic experience of a product. This means that listening and analyzing sound enables them to understand more the integrative aspects of product and embodiment design. The course leaders and the students are therefore very satisfied with the general educational goals of this course. However, one can always make small modifications to make the course more relevant and instructive. The informal character of the meetings makes it easy for the students to feel involved in the projects.

This leads to high quality solutions and deliverables, and it facilitates students to develop their competence on product sound design. The first time a course is held it is hard to find a balance between providing information and instructions on the one hand, and letting students free to choose their own design problem and method on the other hand. Although some students will always request additional guidance, the current approach worked out well: it challenged the students' creative abilities as designer. Many design methods lead to the design of products, but each designer also has to choose which methods fit him or her best. These positive experiences contribute to the development of their own design methodology.
A beautiful design will only be valuable after successful testing. Therefore, if a project team proposes certain improvements, then tests are needed to evaluate the effect of the proposed improvement. A facility for prototyping should be created or made available in the faculty. Only then will it be possible to implement valuable auditory improvements in the product design.

5 CONCLUSION

Products with a high sound quality can only be designed with a solid knowledge on interaction design, sound perception, and the relation between mechanical product properties and resulting auditory attributes. The Product Sound Design course fills the gap that exists between sound experts and product designers. Both have a product vision which should be integrated to the product sound vision for domestic appliances. This creates a new profession, which is valuable and tangible for the education program of industrial design engineering. Product Sound Design fits well in the education system, because students can develop their own competence with this course through hands-on experience and supportive lectures, and as such build up an identity of a product sound designer. This elective master course needs further development before it can be part of the compulsory education program. However, each year steps are taken, and projects supported by the industry should bring the course a big step forwards.

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