Chapter 13
Information and communication technology & manufacturing industries

Designing auditory alarms for an industrial control room

Anna SIRKKA, Johan FAGERLÖNN, Stefan LINDBERG, Katarina DELSING

Interactive Institute Swedish ICT, Piteå, Sweden

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1. Introduction

Constantly increasing and more complex information flows in industrial control rooms raise the risk that operators will become distracted, confused, and visually overloaded during demanding situations. New multimodal interfaces could offer better solutions.

In this work, we focus on alarm sound design. Alarms serve to alert operators to deviations from normal conditions and enable operators to react appropriately. The speed and accuracy with which operators can identify alarms are crucial to their effectiveness. Additionally, auditory alarms should not be too annoying or distracting. Salient auditory stimuli effectively catch and guide operators' attention, regardless of their visual focus. Research has established that auditory signals can be designed to express different levels of urgency and that sound can convey detailed information. However, auditory alarms are often implemented carelessly, using arbitrarily selected sounds that are too loud, too many, and too confusing.

The aim of this work was to develop an auditory alarm concept to improve operator effectiveness and acceptance. A control room in a paper mill in northern Sweden was identified as an appropriate target environment. Seven production sections were monitored from the mill's control room.

2. Auditory Alarm Concept

The developed concept consists of new alarm sounds, spatial presentation of the sounds, and alarm repetition intervals. The sounds convey information about urgency and about the production sections.

Two alarm sounds (representing two levels of urgency) were designed for each of the seven production sections. The sounds were based on the design principle that each alarm sound should have two parts. The first part conveys urgency information, and the second part (an auditory icon) information about the section in question.

The character of the alarms' urgency part has its origins in acoustic musical instruments. Natural harmonics, long decays, and soft attacks were used to create signals designed to be pleasant to listen to.

The sounds belonging to each section have unique characteristics (regarding timbre, melody, frequency content, etc.). Combining spatial presentation with these unique characteristics makes it easier for the operators to distinguish the alarm sounds.

3. Method

This concept was developed through a user-driven design process involving 24 operators working in the target environment. The process consisted of an initial workshop followed by approximately 25 design iterations. Each iteration had two steps: the development of a design proposal and then user interaction. During the user interaction, a sound design proposal was presented to three to six operators, who discussed it. The feedback from the operators formed the basis for the development of a refined design, which could entail anything from the development of new alarm sounds to minor sound level adjustments.

The unfinalised concept was implemented in the control room for approximately 10 months. The concept was further developed as it was utilised in the real-world control room environment. The finalised concept was then implemented for approximately 2 months.

Operator acceptance was assessed through a questionnaire using the Van der Laan acceptance scale. Participants were asked to rate the perceived usefulness of the sounds on five 5-point scales ranging from useless to useful, bad to good, superfluous to effective, worthless to assisting, and sleep-inducing to alertness-raising. Similarly, the perceived satisfaction of the sounds was rated on four 5-point scales ranging from unpleasant to pleasant, irritating to likeable, annoying to nice, and undesirable to desirable.

The same questionnaire was administered twice, once before the design process and implementation and then to evaluate the finalised concept (i.e. the result of the design process). Twenty-one subjects, 2 females and 19 males, participated in the pre-study questionnaire. Their mean age was 43 years (SD 11), and they had a mean of 19 years' (SD 11) experience as operators. Twenty-two subjects, 2 females and 20 males, participated in the post-study questionnaire. Their mean age was 46 years (SD 9.1), and they had a mean of 21 years' (SD 11) experience as operators. All participants in both questionnaires were arbitrarily chosen from among the 24 operators working in the target environment. Consequently, it can be assumed that many operators participated in both questionnaires.

4. Results

The Van der Laan acceptance scale ratings ranged from +2 to -2. Usefulness increased from -0.82 (SD 0.73) to +0.70 (SD 0.56), and satisfaction from -1.05 (SD 0.77) to +0.84 (SD 0.69).

The results of the pre- and post-test questionnaires were statistically analysed. Both independent t-tests and Mann-Whitney U-tests showed that the differences between the pre- and post-study ratings were statistically significant ($p<0.01$) for both dimensions. These results demonstrate that the developed concept increases operator effectiveness and acceptance.

The results provide an example of how control room alarms can be improved. The design principle could be utilized in other industrial plants and contexts, although the specific sounds designed for the present control room might not be directly applicable.

The potential benefits of an exoskeleton in industry settings

Michiel DE LOOZE, Leonard O'SULLIVAN

TNO, Hoofddorp, The Netherlands
University of Limerick, Ireland

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1. Introduction

Various manual work tasks necessary to industrial manufacturing processes are difficult to automate – even today - due to their complexity. This is particularly the case in assembling and dismantling operations, such as those used in the automotive or food processing industries, where material handling and heavy-goods lifting are typically carried out by shop-floor workers. This type of work entails severe risk of injury, resulting in low job productivity, high long-term dropout rates, and even disability. To overcome these challenges, a new project, called Robo-Mate, has been designed.

The objective of Robo-Mate is to develop an intelligent, easy-to-manoeuvre, and wearable body exoskeleton for manual-handling work. The fundamental idea behind Robo-Mate is to enhance work conditions for load workers and facilitate repetitive lifting tasks, thereby reducing the incidence of work-place related injury and disease. As a consequence, productivity, flexibility and the quality of production will increase.

Exoskeletons can readily be found in certain fields and their development to date has been mainly driven by military and medical applications. However, such models are ill-suited for industrial use due to excessive weight or inadequate functionality, such as not being able to provide the lifting and/or manual handling support indispensable to industrial settings. Therefore, developing an exoskeleton specifically destined for use in industrial environments is crucial.

The first steps in the project is to analyze the needs for an exoskeleton, to formulate a use case (to focus on in development), and then to come to a list of prioritized requirements to fulfill.

2. Methods

The question about the needs have been answered on the basis of a literature review, stakeholder interviews and expert sessions, both on the macro-economic level, the meso-company level and the micro-worker level. On that basis functional requirements have been formulated. Both needs and functional requirements have been generated as input for a Quality Function Deployment (QFD) table. Data was further analysed to establish and prioritize specific elements for the design of the exoskeleton system.

3. Results

Based on the industry needs, the following two cases were defined for further elaboration into design needs and specifications:

- Use-case 1: frequent two handed lifting of loads of medium weight (up to 15 kg)
- Use-case 2: one handed manual operations (assembly or disassembly) in stressful body posture
- The major outcomes from the QFD analysis are
- The data indicates the stakeholder's top priorities for the concept design are safety and usability.
- The data indicates that the exoskeleton should be designed to comfortably be worn by the user (anthropomorphic fit and thermodynamic comfort), and that it should stabilise movements within the users range of movement. Additionally, the movement of the exoskeleton should match the user's movements and support the body throughout a range of static and dynamic postures while stabilising the movements and minimising compressive forces and muscle loading.
- The data indicates that the exoskeleton should have wide adaptability, is not restrictive in use should easily allow workers to rotate between one and two-handed task, have built in adjustability for users, and enable precise movements.
- The data indicates that the exoskeleton should be risk assessed and trial tested throughout the design process and it should meet all applicable standards and codes of practice. Additionally, the exoskeleton should be designed with other exoskeleton users or ambulatory workers in the vicinity in mind.

An overview of various types of exoskeletons which reflects the above outcomes will be presented at the conference.