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Prediction, Visualization and Auralization of Noise in Industrial Workrooms During Computer 'Walk-Through' – the *PlantNoise* System

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1. INTRODUCTION

In industrial workrooms, in order to limit the risk of hearing loss, as well as to promote the adequate recognition of speech and warning signals, it is necessary to limit noise levels and reverberation times to acceptable levels at work positions. The distribution and levels of noise generated by sources in industrial workrooms are affected by room geometry, construction materials and equipment layout. Acousticians can implement noise-control measures at the design stage of new workrooms by appropriately controlling these factors, as well as by specifying quiet machinery. Noise reduction is also achieved by the use of noise-control measures such as barriers, acoustical enclosures and sound-absorbing surface treatments. In order to achieve sufficient noise control in the most cost-effective way, the acoustical designer needs to be able to evaluate and compare design options. Prediction of the workroom noise can provide useful objective information to a designer who is responsible for ensuring that the acoustical conditions are satisfactory. However, subjective information about the sound field, obtained by listening to the noise, can also be very useful in demonstrating the need for adequate noise control. Subjective experiences can be realized using acoustical-virtual-reality (auralization) techniques.

This paper presents a new approach to industrial-noise modeling, which takes the form of a combined industrial-noise prediction, visualization and auralization system, called *PlantNoise*. The system is designed to predict and present noise to a listener in a way that accurately simulates the noise levels that a worker in a workroom would be exposed to. A graphical user interface allows the user to visualize virtual location within the workroom and to 'walk-through' it, experiencing the noise updated in real time. Total and octave-band noise levels and octave-band reverberation times are displayed to the user. New empirical models are used to predict the noise levels and reverberation times. A major objective of this work was to develop a system that is readily accessible to acoustical consultants, industrial hygienists, suppliers of noise-control products and other professionals.

2. SOUND-FIELD PREDICTION

Noise levels and reverberation times, in octave bands from 125 to 4000 Hz, were predicted using novel empirical models. These were developed using multivariable linear-regression analysis of experimental data from 30 'typical' industrial workrooms. The workrooms were either empty or fitted. Some contained sound-absorptive treatments. Details of the models and their derivations and evaluation are presented elsewhere [1].

3. INPUT DATA AND SYSTEM OPERATION

The operation of *PlantNoise* is straightforward. A data-file contains all workroom-specific information, including dimensions, surface types, source sound-power levels and information on the workroom fittings. All other information required by the *PlantNoise* system, including headphone and soundcard calibration constants (see below), surface-absorption coefficients and A-weighting constants, is contained within the main executable. Input data describing the workroom are grouped into three categories, as detailed below, along with the adjustable input parameters for each case:

Fittings - proportion of floor area covered, average fitting height, number of fittings; Sound sources - description, coordinates, octave-band sound-power levels;

Surfaces and absorption - area of hard (concrete, etc.) surfaces, area of paneled (steel-deck roof, metal cladding, doors, etc.) surfaces, area of acoustically treated surfaces, octave-band absorption coefficients of the acoustically treated surfaces, octave-band air-absorption exponents. Presumed absorption coefficients for the hard and paneled surfaces are built into the prediction models; those for the treated surfaces are user-defined.

After first reading in the workroom data, the program visualizes the workroom floor plan, with sound sources and a 1-m receiver grid superimposed, and the sound-level / reverberation-time displays. Noise levels at the default receiver position, as well as reverberation times, are calculated and displayed. The program initializes the soundcard, loads octave-band noise files, and commences noise generation based on the predicted noise levels at the receiver position. The user can then 'walk-through' the workroom by moving the receiver icon to any grid position bounded by the four walls. The user is able to interact with the simulation, and experience the visualized and auralized noise levels, while 'walking-through' the virtual workroom on the screen. Noise contour maps can be plotted at any time. Furthermore, at any time the workroom can be modified - for example, to simulate and test noise-control measures - by adjusting the workroom parameters; the new noise is visualized and auralized and new maps are plotted.

Figure la is a simulated *PlantNoise* visual display, showing the floor plan of a moderately-densely-fitted workroom with dimensions of 61 m by 34 m by 5 m high, containing four noise sources (total sound-power levels of 95, 95, 100 and 105 dB, respectively). The workroom has 3024 m^2 of hard surfaces (the floor and walls), 2074 m^2 of paneled surfaces (the steel-deck ceiling) and no acoustical treatment. The smiley-face icon represents the receiver position. The lower central portion of the screen displays graphically the octave-band sound-pressure levels at the receiver position. The levels are updated in real time during 'walk-through', and after parameter adjustments. Also displayed are the predicted octave-band reverberation times, which do not change with receiver position. They are updated only when workroom parameters are adjusted - for example, to reflect the effect of the addition of acoustical treatment to the workroom.

4. AURALIZATION

Noise generation involves a sound-card replaying anechoic, octave-band noise corresponding to the predicted octave-band sound-pressure levels at the current receiver position, using octave-band noise files resident in the card's DRAM memory. The objective of the auralization component of the system was to replicate octave-band noise levels as accurately as possible. To this end, calibration is required for the sound-output devices used in system - the Sennheiser HD480 headphones and the SoundBlaster sound-card. Both devices exhibit non-linear responses in both frequency and magnitude, requiring compensation to achieve a linear input/output transfer function for the system as a whole. A more significant problem is that of the filtering of sound by the external ears. The assumption of a diffuse sound field was made. The objective was effectively, therefore, to simulate levels corresponding to a diffuse sound field at a listener position, using diffuse-field head-related transfer functions. In order to achieve the desired diffuse-field simulation, the headphone/ear transfer function and hardware non-linearities must be removed from the overall system transfer function, and the diffuse-field head-related transfer functions applied.

5. SIMULATING NOISE-CONTROL MEASURES

There are two common workroom noise-control measures that can be simulated and tested using *PlantNoise*. The first is the application of sound-absorbing acoustical treatments to the room surfaces to increase the average surface-absorption coefficient. The second consists of installing acoustical enclosures around noisy equipment to reduce the radiated output power. To illustrate how such treatments can be simulated with the *PlantNoise* system, consider the noisy workroom shown in Figure 1a, and discussed above.

As indicated by the noise contours, levels in the untreated workroom varied from 77 to 93 dBA, being highest in the vicinity of dominant source 4. The reverberation time was about 1.8 s. Subjectively, the noise was very loud, and was annoying due to its dominant high-frequency content. Acoustical treatments were applied as follows:

1. Absorptive surface treatment - covering the ceiling with an absorptive treatment was accomplished by modifying the relative areas of the paneled and treated surfaces. 2074 m^2 were subtracted from the panel-surface area and added to the treated-surface area. The absorption coefficients of the treatment were also entered - in this case values increasing with frequency from 0.4 to 0.8 were used to represent suspended baffles;

2. Enclosing a sound source - enclosing a sound source was accomplished by reducing the source sound-power levels by an amount equal to the attenuation expected from the enclosure. In the present example, the total sound-power output of source 4 was reduced by 15 dB.

The simulated *PlantNoise* display in Figure 1b shows the noise levels and reverberation times after the addition of the surface treatment and the enclosure of source 4. Noise levels have been reduced by 10-15 dBA. The reverberation time has been reduced to about 0.6 s.

Subjectively, the loudness was more than halved and the noise was less annoying, since the acoustical treatments resulted in the high-frequency noise being less dominant.

6. CONCLUSION

Numerous improvements in *PlantNoise* are planned or currently being implemented. It could be extended to predict noise exposure from worker time/motion information [2]. There is considerable potential for improving the realism of the subjective experience provided by the auralization component of the system. For example, the system could be extended to allow simulation of the radiation by noise sources of pure-tone and impulsive sounds. Equipment-noise signatures could be recorded, digitized and stored in the system for replay at predicted levels. Reverberation could be superimposed on the predicted noise.

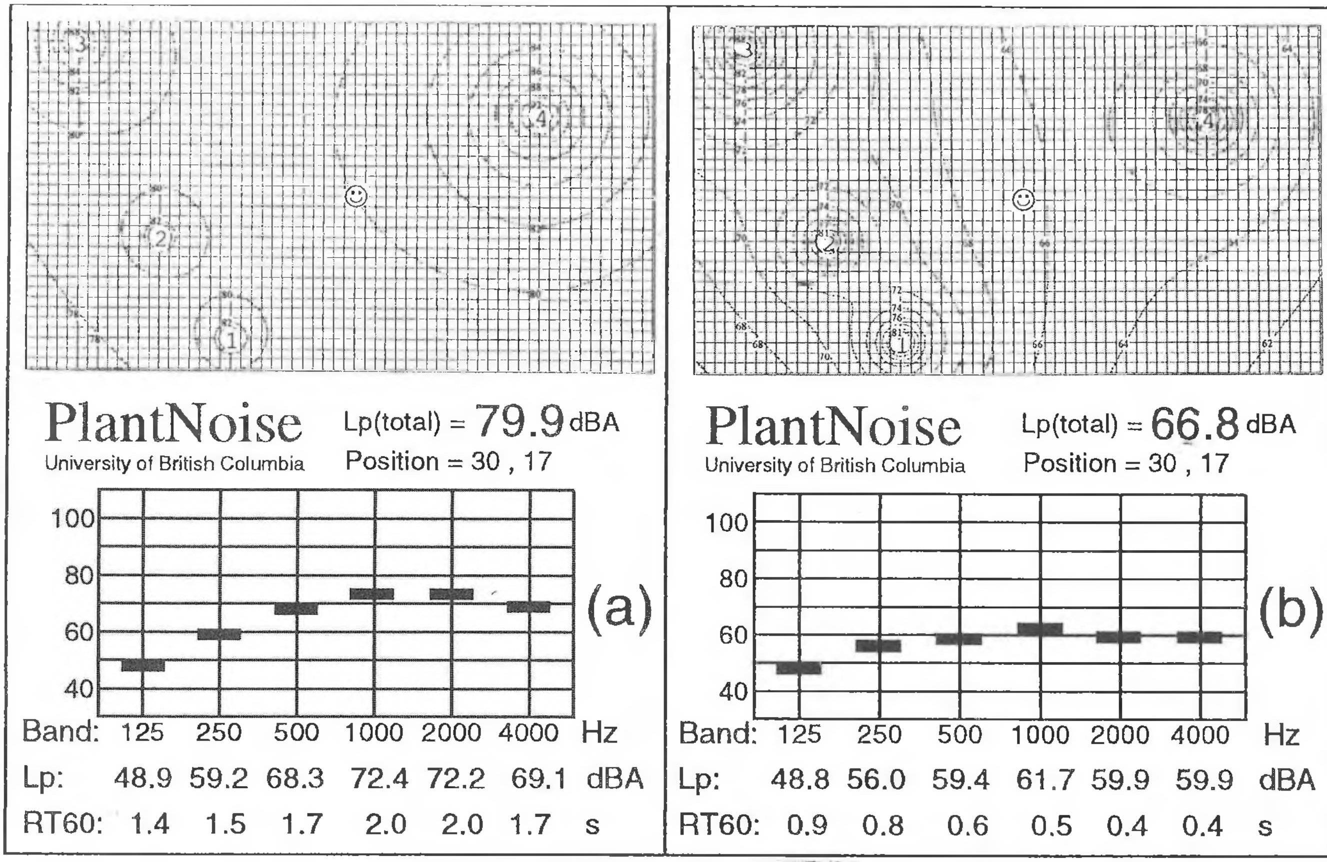

FIGURE 1. Simulated PlantNoise visual displays, showing A-weighted noise levels, and reverberation times, in a large, fitted workroom (a) before treatment; (b) after treatment.

7. REFERENCES

1. N. Heerema and M. R. Hodgson, "Empirical models for predicting noise levels and reverberation times in industrial workrooms", *Appl. Acoust.* 57(1) 51-60 (1999).

2. A. M. Ondet, "Prediction of occupational noise exposure", *Proc. Internoise* '96, 3035-3038 (1996).