FACTORY NOISE COMPUTER PREDICTION USING A COMPLETE IMAGE-SOURCE METHOD

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1. INTRODUCTION.

Computer modelling for the prediction of sound distribution in factory spaces has been extensively researched during the last ten years. The Ondet and Barbry program, Raycub [1], has emerged as the most accurate computer model, with many authors [2-4] independently testing their own data to validate the model. The problem found with the Raycub model is the time required to both run the program and to enter the detailed information necessary to represent an enclosed space.

To overcome these practical shortcomings of Raycub a new model, the Complete Image-Source Method (CISM), has been written. CISM is an image source model which incorporates those representational features of Raycub which have been found to have the most effect on prediction accuracy [4]. This approach reduces both the run-time of the model and the amount of data necessary to represent a space.

This paper describes the original version of Raycub and the development of the CISM model, and compares both the prediction accuracy and run-time of the two models in four industrial enclosed spaces.

2. THE ONDET AND BARBRY MODEL RAYCUB

The Ondet and Barbry computer model Raycub is based on ray-tracing of discrete sound paths, the rays randomly emanating from a point source omni-directionally and being specularly reflected from the surfaces defined within the model. [For a full description of the Raycub model see reference 4.]

The space can be divided into many zonal volumes each of which represents a distinct group of fittings. Each zonal volume has two associated parameters, the scattering frequency and average absorption coefficient of the fittings.

When a ray has travelled on average the reciprocal of the scattering frequency inside a zone it is randomly reflected and attenuated by the absorption coefficient.

A factory requires a large number of rays to accurately model the space, usually ten times the volume, with each source allocated a proportion based on its sound power. The rays produced by a source all have the same energy and are attenuated by the distance travelled, air absorption, surface absorption and the absorption of the fittings. The receiver points are represented by a transparent mesh of cubic cells. The rays travel thorough the cells, each ray contributing a proportion of its energy to the total energy contained within a cell.

3. THE CISM MODEL.

CISM is based on the Image-Source method of geometric computer modelling rather than the ray-tracing technique used by Raycub. The description of the sound paths in an Image-Source method is inherently more accurate than in a ray-tracing model [5] and it will be shown that the run-times of CISM are considerably less than for Raycub, while the prediction accuracy is maintained.

3.1 Modelling the Geometry of the Space.

The CISM model assumes the enclosed space to be parallelepiped, see Figure 1, with each surface having an associated absorption coefficient. This simplification can be justified for typical fitted factories as an exact description of the geometry has been shown to only marginally improve prediction accuracy [4].

3.2 Modelling the Fittings in the Space.

Equipment, stock or machinery can be considered as fittings. CISM represents the fittings using two zones, one situated near the floor and the other near the ceiling; an example of floor zoning is shown in Figure 1. CISM treats each zone as a continuous medium which attenuates the sound path, the attenuation depending on the scattering frequency [6] and the average fitting absorption coefficient. The attenuation, F, for a fitted zone, is given by

$$F = (1-\alpha)^{|d| \cdot q}, \quad q = \frac{\sum_{f=1}^{m} S_f}{4V}$$

where q is the scattering frequency of the fitted zone, d is the distance travelled by the ray in the zone, α is the average absorption coefficient of the zone, m is the number of individual fittings in the zone, S_f is the surface area of a fitting and V is the volume of the zone.

3.3 Modelling the Sources in the Space.

CISM represents a source as a point in 3-dimensional space, with an associated sound power. A source may be assumed to be omni-directional, or its directivity can be approximated using directivity factors for twelve points equally spaced round the source.

A disadvantage of the model is that it cannot represent the back-scattering effect where sound reflects towards the source from nearby fittings. This has been shown by Hodgson [7] to affect the near field measurements of the source. Incorporating source directivity can partially compensate for this phenomenon as the in-situ directivity approximation is affected by back-scattering.

4. DESCRIPTION OF THE INDUSTRIAL SPACES.

Measurements made by Jones [8] in three fitted factories and one empty space were chosen to demonstrate the prediction accuracy of CISM as compared to Raycub. For both models, the problematic measurement in accurately describing a factory is that of the surface area of the fittings, which is required to calculate the scattering frequency. This area is impossible to measure in operating factories, so an approximation is calculated by taking the surface area of a box, the dimensions of which are the outer dimensions of the fitting. The four cases used in the validation of CISM are described below.

Case 1. This was an empty space of dimensions 54m by 16m with a pitched roof, rising from 10.6m to 14.6m. The walls were all of a brick construction;

the ceiling was two-thirds panelled and one-third glazed; concrete covered the floor; and situated at one end was a small office. A single speaker was used as a sound source.

Case 2. This was a duct shaped fitted factory with a length of 108m, a width of 24m and a height of 10.9m. The wall construction was a combination of brick, plastic panels and glass, the ceiling being plastic panels and perforated fibre board with a mineral wool infill. The fittings fell into four groups: half the floor area was used as a storage area for small steel boxes, a quarter for metal-working machines, the remainder of the floor space for metal workbenches, and the roof contained one rail crane and associated fittings.

The space was modelled twice due to the complex layout of the fittings: first, with a loudspeaker as the only noise source (Case 2a) and secondly with thirteen metal working machines operating (Case 2b).

Case 3. The third space was 75m by 40.8m with a rectangularly corrugated roof from 12.2m to 13m high. The building had a modern steel frame construction with walls of aluminium, concrete and brick; the floor was of concrete; and the light-weight aluminium ceiling contained a rail crane across its full width. Offices were situated in the corner forming three internal surfaces. The noise sources were seventeen large metal working machines which were arranged in three lines.

Case 4. A brewery packaging plant formed the fourth space with dimensions of 80m by 53m and a multi-pitched roof rising from 7.3m to 10m. The brewery had a modern construction with painted brick walls, a concrete floor, and a ceiling of plastic on fibreboard backed to aluminium. The fittings were all metal and evenly distributed around the floor area. An office was situated across the full width of the factory at one end. There were three types of noise source: filling machines, air jets and conveyor belts.

5. VALIDATION OF CISM AND RAYCUB.

In each case, the two models were used to predict overall sound levels at receiver points distributed around the space. The predicted levels were compared with noise levels measured at the receiver points and the average errors calculated.

5.1 The Raycub Space Representation.

The Raycub model used a representation, described in reference 4, consisting of 90% energy discontinuity, that is at least 90% of a ray's energy is attenuated before the ray is assumed to terminate. The receiver cell size was $1m^3$, the minimum size possible, which has been shown to give the most accurate results [4]. The space was described by complex geometry; the sources were assumed to be omni-directional; and fittings were represented as accurately as possible using full zoning. An example of this Raycub representation for a typical fitted factory is shown in Figure 1.

5.2 The CISM Space Representation.

The CISM model represented the spaces using source directivity, an average absorption coefficient for each surface, the average room dimensions, floor zoning and the same reflection order as used by Raycub, calculated using the energy discontinuity percentage. An example of the CISM representation of a typical fitted factory is shown in Figure 1.

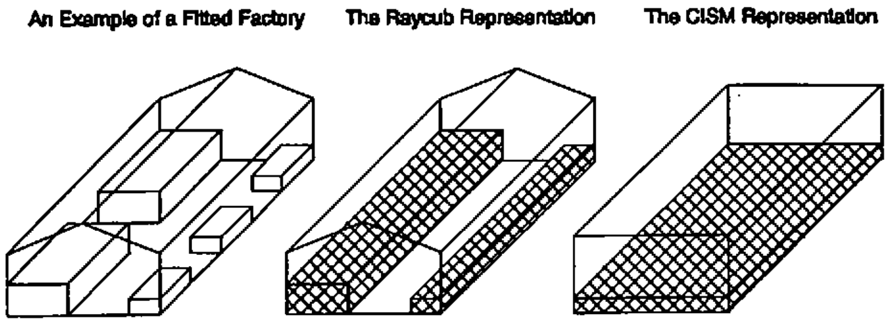

Figure 1. A comparison of the zoning and geometric represention used in the prediction models.

5.3 Results

Tables 1 and 2 show a summary of the predicted results for each case when modelled using both Raycub and CISM. The tables give the average error, (predicted minus measured sound level in linear dB); the percentages of the receiver points where predictions are within 1 to 4 dB of the measured noise levels; and the execution times for the models using a 486-25 PC.

TABLE 1 Prediction Summary for Spaces with a Speaker as Sound Source

	Case 1 CISM	Case 1 Raycub	Case 2a CISM	Case 2a Raycub
Error (dB)	0.5	1.6	1.2	1.5
% 1dB	84.6	5.1	53.6	40.4
% 2dB	97.4	82.1	86.6	66.0
% 3dB	100.0	94.9	97.3	93.6
% 4dB	100.0	97.4	97.3	97.9
Time	35s	1h 15m	2m 5s	2h 1m

TABLE 2 Prediction Summary for Spaces with Machines as Sound Sources

	Case 2b CISM	Case 2b Raycub	Case 3 CISM	Case 3 Raycub	Case 4 CISM	Case 4 Raycub
Error (dB)	1.0	1.1	1.5	0.9	1.0	1.1
% 1dB	44.4	46.7	57.1	71.9	52.2	44.8
% 2dB	94.4	79.3	86.9	89.1	85.1	82.1
% 3dB	100.0	97.8	94.0	98.4	100.0	98.5
% 4dB	100.0	100.0	94.0	98.4	100.0	98.5
Time	21s	2h 1m	2m 30s	2h 22m	2m 39s	4h 30m

6. DISCUSSION OF RESULTS.

As can be seen in Table 1 the CISM model is significantly more accurate than the Raycub model in the spaces with a loudspeaker as the sound source. The main reason for this improvement in prediction accuracy is the strength of the source directivity of the loudspeaker. The source is modelled as omni-directional by Raycub, but the directivity is approximated by CISM. Table 2 shows that with machines as sound sources the prediction accuracy is similar for both Raycub and CISM.

The major difference between the two models is the length of the run-time, with CISM executing in approximately one-hundredth of the time of Raycub in all cases. Both models give an average prediction error of less than 1.6dB with over 80% of predicted levels being within 2dB of the measured sound levels in most cases.

7. CONCLUSION.

A complete implementation of the Image-Source method has been developed from the knowledge gained in using the Raycub model. The model has been shown to be accurate in four factories, giving similar results to Raycub, with all the spaces having an average error of less than 1.5dB. Using CISM, over 85% of predictions are within 2dB of the measured sound levels. The results indicate that the CISM method of modelling fittings as simple attenuators gives the same accuracy as when fittings are modelled as both attenuators and scatterers of sound, as in Raycub.

The run-time of CISM is, on average, one-hundredth that of the original Raycub model, and CISM requires significantly less data than Raycub to accurately represent a space.

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