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AN IMPROVED USER-INDEPENDED ALGORITHM FOR ROOM ACOUSTIC PARAMETERS CALCULATION

Panagiotis Charalampous, Panos Economou
P.E. Mediterranean Acoustics R&D Ltd, Limassol, Cyprus

We present a novel algorithm for room acoustic parameters calculation which addresses one of the major uncertainties in room acoustics prediction, that of user defined termination criteria. One of the uncertainties in room acoustics predictions that take place using geometrical acoustics methods is the user defined termination criteria. Ray tracing algorithms require maximum length and number of rays to be send. Image source algorithms require maximum reflection orders and/or maximum sound attenuation. Our algorithm adjusts progressively its termination criteria until a correct result is approximated, based on an intelligent guessing, therefore removing this burden and risk from the user. We explain the algorithm's termination procedure and we compare with typical implementations. We show that the results approximate measurements equally well or better, having the benefit that the user does not need to worry anymore about these settings.

1. Introduction

Room acoustic modeling and computer simulation is one of the major tasks undertaken by acoustic engineers nowadays. The design of interior spaces like concert halls, theaters, recording places, classrooms and many more is depended upon accurate modeling and calculation of several parameters related to sound. For this reason, several algorithms have been presented throughout the years and many software packages that assist the user to model interior spaces have become commercially available. Nevertheless, modeling and calculations are complex and time consuming procedures that require the input of an experienced user. Thus, the responsibility to properly model and calculate correct results lies mostly on the shoulders of the engineer. One of the important decisions that need to be taken by the user of a room acoustics modeling software is usually the algorithm's termination criteria. Most of the commercial software tools require from the user to specify various termination criteria related to the algorithm they use, like number of rays, maximum length of rays, order of image sources etc. The reliability of the results is highly related to the user's decision, consequently increasing the risk for unreliable calculation results. In this paper, we demonstrate how room acoustics calculation results change based on user's decisions and we present a new algorithm that automatically adjusts its termination criteria, something that redounds to better results and most importantly to user independence.

2. Background

Room acoustics computer modeling is a research area with a history dating back to the 50s [1]. Extensive reviews of the subject are available [2] [3]. In brief, two major types of techniques have been developed. These are deterministic tracing techniques and stochastic tracing techniques. Deterministic techniques are methods which will yield the same result after repetitive runs. Such techniques are the image source and beam tracing. Stochastic techniques are Monte Carlo methods which attempt

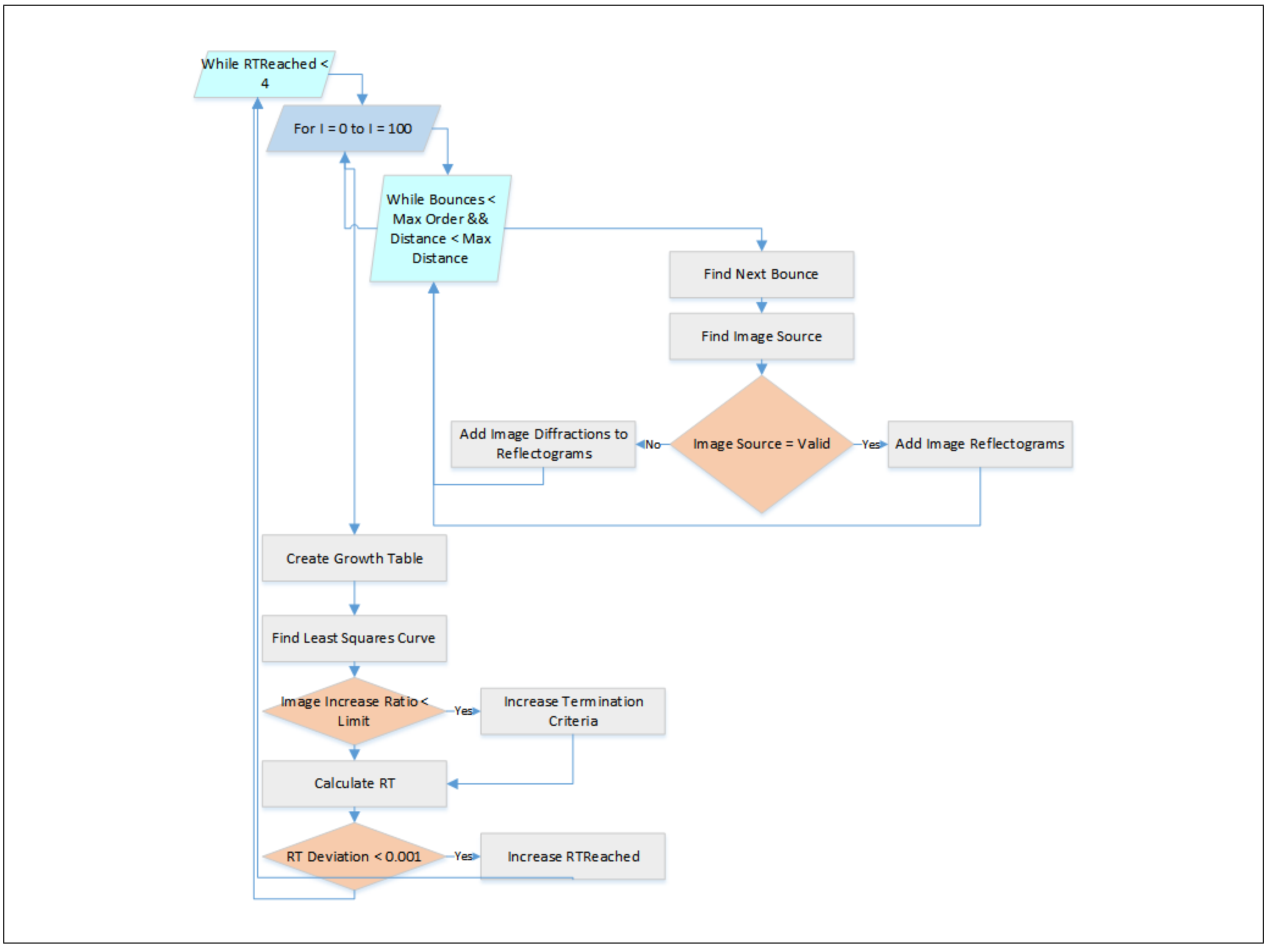

Figure 1: Algorithm Flowchart.

a statistical approximation of the sound field and their results might differ between subsequent runs. Examples of such techniques are ray tracing, particle tracing and frustum tracing.

Over the years, many of the proposed room acoustics modeling algorithms have found their way into commercial and non commercial applications [4] [5] [6] [7]. In spite of that,one of the conclusions that have emerged from the three round robins held for room acoustical computer simulations is that most of these software applications require a level of expertise in order to be used correctly [8] [9][10]. The 1st round robin revealed great discrepancies in the calculation results which where attributed to a) the users input b) lack of scattering calculations c) and the determination of termination criteria, like maximum orders of reflection and rays to be traced. The 2nd round robin confirmed that the calculation results are depended greatly on the skills of the user. The 3rd round robin has also shown that user mistakes can affect significantly the calculation results. The conclusion is that the calculations reliability relies on two major parameters. The first one is the accuracy of the 3D model and the material data. The closer the representation and the data are to reality, the better the results. The other parameter is the determination of algorithm's termination criteria. Termination criteria are usually the order of reflections (image source algorithms) or number of bounces (tracing algorithms), the number of rays shot (in the case of stochastic algorithms) and the distance of the sound paths from source to receiver. The number of the detected rays is one of the major uncertainties present in contemporary computer simulations for room acoustics [11]. In this paper, we demonstrate how the termination criteria can be automatically decided by the software, thus increasing the accuracy of the calculations and minimizing their user dependence.

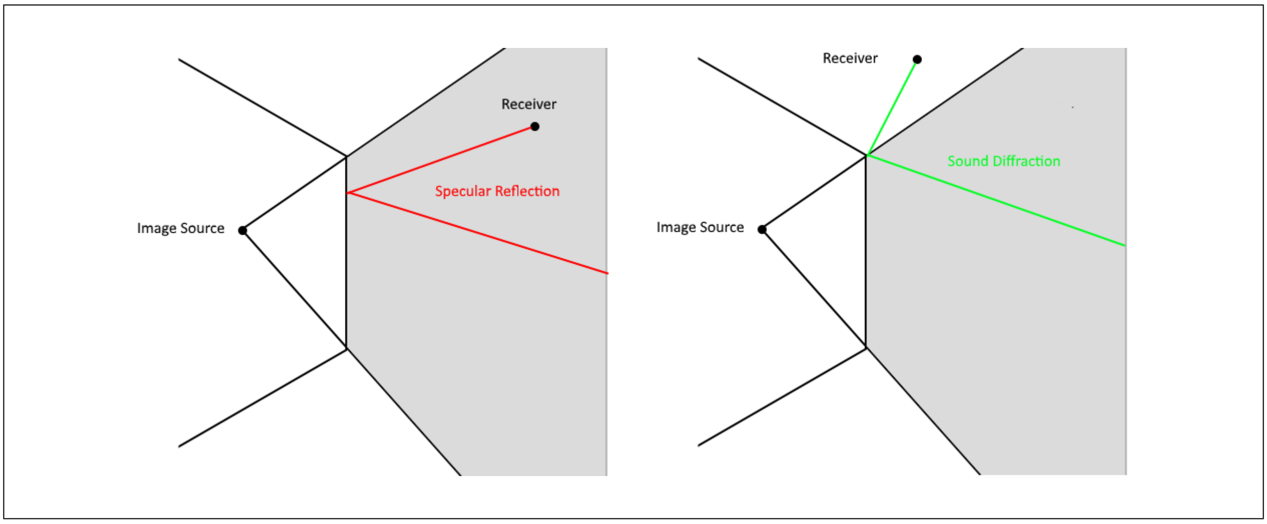

Figure 2: Image Source Edge Diffractions.

3. The Algorithm

Our algorithm is a hybrid implementation combining ray tracing and image source [12] extended with sound diffractions from images together with automating evaluation of termination criteria at run time. It can be split into two major parts a) tracing b) results evaluation and criteria readjustment. The algorithm is explained graphically in the flowchart in Fig. 1. In brief, the process can be summarized as follows a) 100 rays are send b) The specular reflections and the image source edge diffractions detected are evaluated and added to the 1/3 octave reflectograms c) Termination criteria are adjusted if needed d) results deviation is evaluated and the loop goes back to (a) or terminates accordingly.

3.1 Tracing

As mentioned above the tracing part of our algorithm is based on Vorländer [12] and extends it by also detecting sound diffractions from image sources. The addition of edge sound diffractions from images allows a more accurate and physically correct simulation of the scattering phenomenon in interior spaces.

3.1.1 Image Sources

The image source detection process goes as follows a) a ray is casted from the source and propagated through space b) as soon as the ray hits a surface, the surface's image source is generated and recorded c) the ray is reflected from the surface d) steps b and c are repeated recursively until the termination criteria are met. The termination criteria are the number of ray bounces and the distance traveled by the ray and they are adjusted during run time (this is discussed later on) e) on meeting the termination criteria, the ray is neglected and the image sources recorded during ray tracing are evaluated for their validity. Valid image sources are used for the estimation of the impulse response. Implementation details of this process have been discussed numerous times in the past [13][14][15][12][16][17], hence they are neglected and are out of the scope of this paper.

3.1.2 Image Source Edge Diffractions

In the above process an extra step is added, that of the detection of image source edge diffractions from the image's surface. The image source edge diffractions are only detected whenever the receiver does not fall in the field angle of the image source. Thus, an image source can contribute to the sound field either with a specular reflection on a diffraction from its surface edges. A graphical explanation

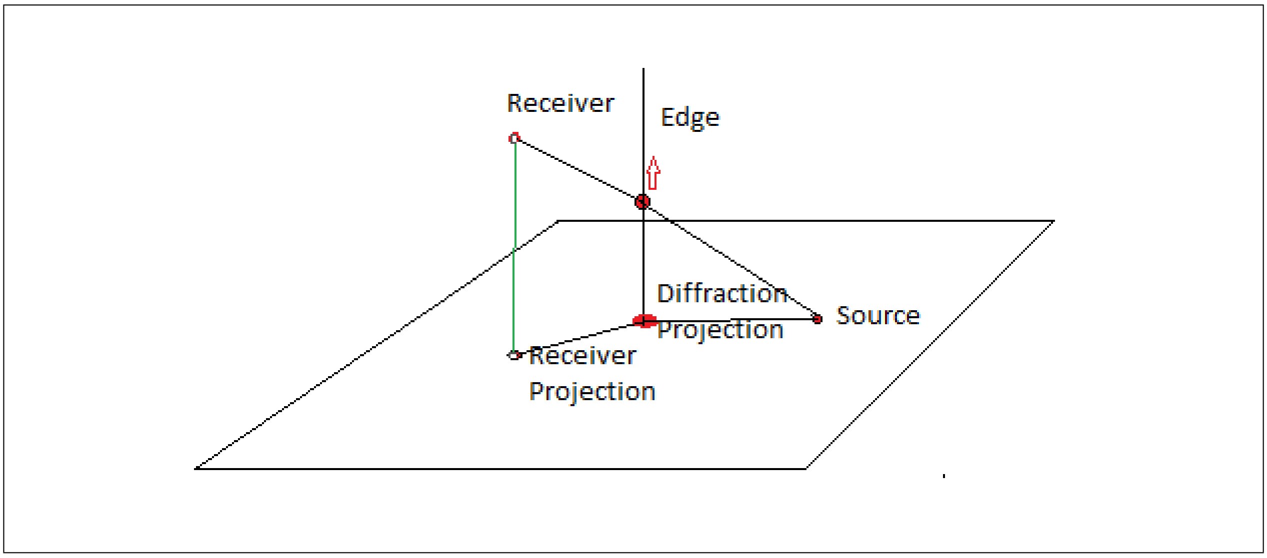

Figure 3: Edge Diffraction Detection.

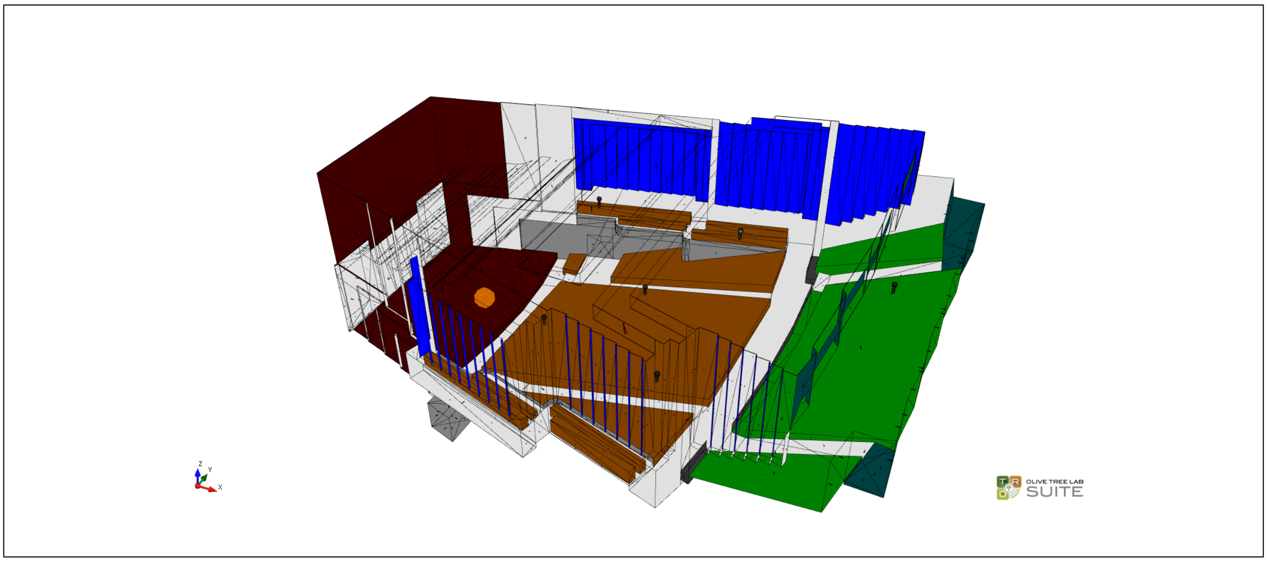

Figure 4: Elmia Hall Model.

is given in Fig. 2. The image source edge diffractions are constructed by finding the shortest path connecting a source, an edge and the receiver (Fig. 2). Following on, we provide the steps required to detect the diffracted path

1. We get the infinite line on which the edge is on.
2. We find the plane that is created from the source point and the infinite line vector.
3. Based on the above, we estimate the distance we need to move the projected diffraction.

The process is graphically depicted in Fig. 3. Since for each surface there might be more than one valid diffraction paths, for each image source we consider only the shortest diffraction path to the receiver.

3.2 Evaluation and Criteria Readjustment

The differentiation of the algorithm when compared to traditional geometrical acoustics algorithms is the introduction of an evaluation stage during run time and the dynamic adjustment of termination criteria. As seen in Fig. 1, for every 100 rays traced, an evaluation part takes place. This part evaluates the following a) The ratio of increase of valid rays and b) The mean absolute deviation between the last 6 calculated reverberation times. If (**a**) falls under a certain number, this indicates that the tracing has started getting saturated and the termination criteria are increased. The termination criterion increase takes place when the following inequality becomes true

$$Ri < 3Am/Rr$$

Where Ri is the ratio of increase between the total valid images detected up to that moment to the number of valid images at the previous evaluation, A is the ratio of images growth over the impulse response time, m is the mean free path and Rr is the ratio of increase of rays traced.

We used Olive Tree Lab Suite™ and Acoustics Lib© to calculate the transfer function for each path. The transfer function is calculated using the following equation.

$$TR = \frac{e^{jkR}}{R} \prod_{j=0}^{o} C_o \tag{1}$$

Where TR denotes the transfer function of the 3D model, e^{jkR} the attenuation of the sound pressure due to spherical spreading, j the imaginary number, k the wavenumber, R the ray length, o the number of coefficients calculating the effect of respective sound phenomena affecting the sound ray and C the coefficient which represents the effect of each phenomenon on the sound ray. The transfer functions of the paths are used for the construction of the reflectograms which subsequently are used for the calculation of the room acoustics parameters.

Following on, the reverberation time for a single frequency is stored in a list. The frequency is selected after calculating the Sabine reverberation time and picking the frequency with the highest RT. We call this the check frequency and it is calculated as follows

$$\arg\max_{i} f(Sabine(i))$$

Where i is the check frequency.

At each calculation interval, the reverberation time is calculated using the process described in ISO 3382-1:2009 [18].

As soon as the list count reaches 6 reverberation time calculations, then the mean absolute deviation of these calculations is calculated. As soon as the deviation falls under 0.001 then a variable named RTReached is increased. If the deviation does not fall under 0.001 then the RTReached variable is set to 0. The calculation is terminated when the RTReached variable reaches value 4, meaning that for 4 consecutive times the deviation was under 0.001. This fact indicates that the subsequent additions of image sources has not changed the result, thus the actual reverberation time has been approximated. At this stage, the tracing is terminated and the final results are calculated.

4. Results

We compare our algorithm to an equivalent user-dependend (UD) algorithm. The UD algorithm is exactly the same with the user-independed(UI) version with the difference that the ray distance and the number of bounces are set by the user. We ran the UI algorithm using the ELMIA hall model (Fig. 4) used in round robin 2 [9] with the same input data, in order to allow comparison with measurements (See model, Fig. 5). Then we ran the UD version with four different input configurations. We chose the ELMIA hall because the model is widely available as well as some material absorption coefficients. However, the original web page has been taken down, so we had the data provided by third party software vendors. We have also noticed some deviations between the results provided by the software vendors and the round robin findings (the software calculations deviated significantly from the reported calculation in the round robin), therefore we adjusted the model's absorption coefficients until the calculation results of the third party software match the round robin results. Nevertheless, some deviations remaining in the calculation results might be explained

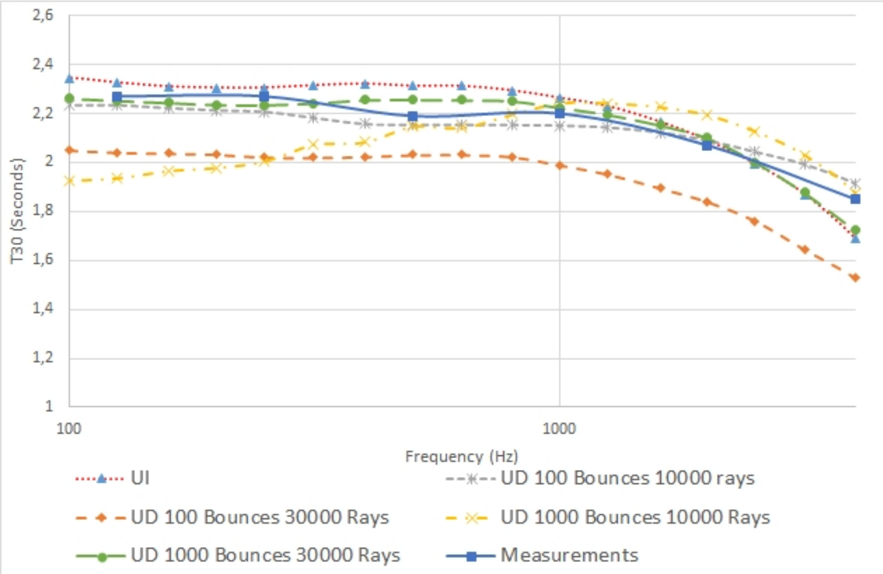

Figure 5: T30 Comparisons.

by the uncertainty in the input data. We compare the results of each run for T30, D50 and Centre Time for Source 1 and Receiver 6, as described in [9]. We show the results in Fig. 5, Fig. 6, Fig. 7. respectively.

5. Discussion

Examining the results, we can see the deviation in the calculated results between the two algorithms. We can notice that the deviation can occur not only by the selected number of rays, something that can be intuitively expected, but also by the selected termination order, which in this case is relatively high in both cases of the UD algorithm. On the other hand, we can remark how closely the UI approximates the results, driven by its internal termination adjustment procedure and the incremental validation of the results. We attribute some deviation observed from the measurement results to the uncertainty of the input data.

6. Conclusion and Future Work

It has been shown that room acoustics modeling algorithms can produce reliable results and calculate accurately several room acoustics parameters but are sensitive to user inputs and their outcome is highly depended on the experience of the user. In this paper, we presented a novel algorithm which removes the burden of deciding the termination criteria from the user, therefore minimizing the risk of unreliable results. The calculations have shown that the algorithm approximates measurements well, in comparison to a similar algorithm with user defined termination criteria where the results deviate significantly between different inputs.

Future work will focus on evaluating the algorithm in different geometrical settings in order to verify the general applicability of this approach. Furthermore, more research will take place for the adjustment and evaluation steps by comparing different adjustment processes and termination conditions which can result in faster execution times.

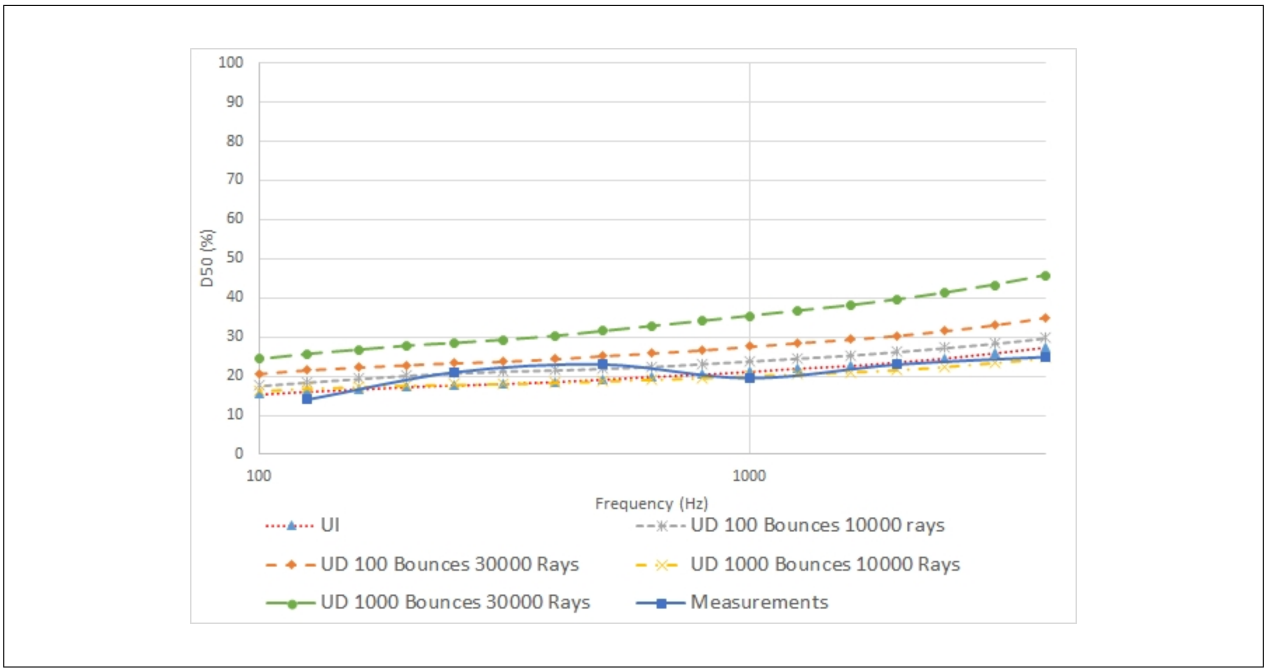

Figure 6: D50 Comparisons.

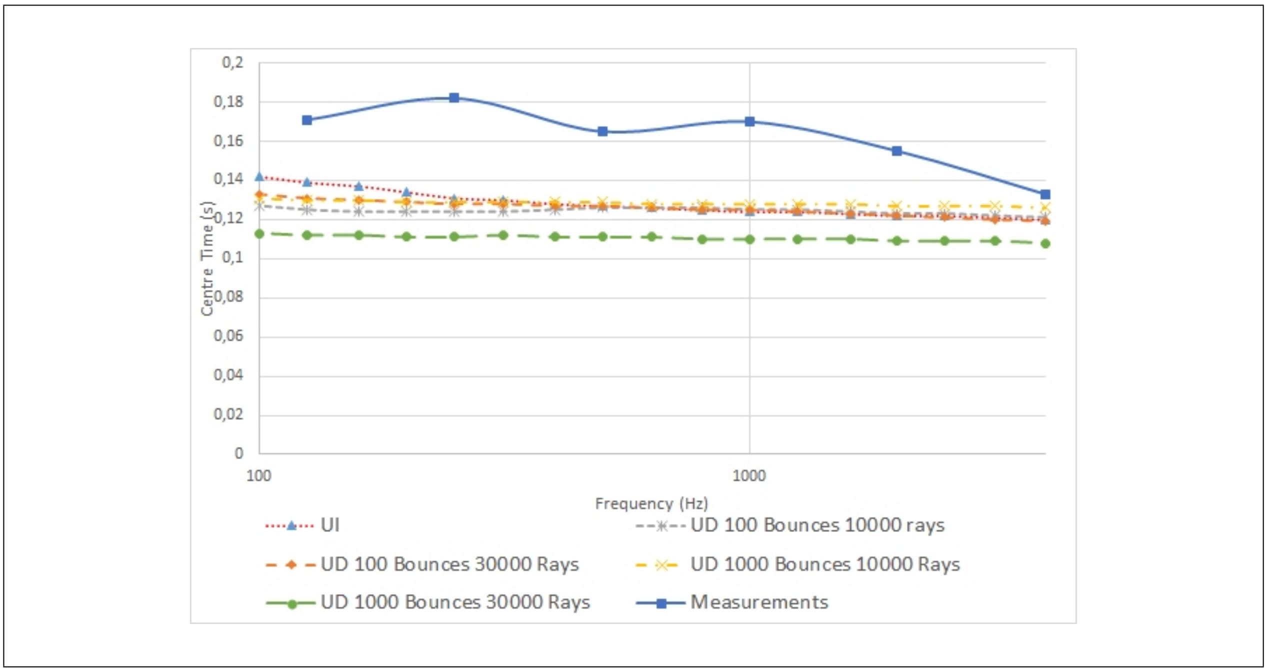

Figure 7: Centre Time Comparisons.

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