

# DEVELOPMENT OF HIGH RESOLUTION 3D SOUND PROPAGATION MODEL USING LIDAR DATA AND AIR PHOTO

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## ABSTRACT:

Prediction of sound level of real world environment in 3D is important for managing noise pollution, urban planning, virtual realization of sound etc. Commercially available semi-empirical sound models use various input parameters such as location of source and receiver; diffraction related path length difference when sound encounters intermediate buildings; characteristics of ground; nature of vegetation etc. Empirical techniques used inside the existing sound models suffer from approximation in algorithm, inadequate technique to feed terrain related information and limitation in capturing accurate terrain information in many cases. Airborne Altimetric LiDAR (Light Detection and Ranging) surveys along with aerial photographs generate accurate high resolution terrain data in a short time. It creates interesting options for feeding intricate terrain information inside these models. In the paper a technique is described for taking input from LiDAR data and air photos to generate terrain related parameters required in empirical approach. Furthermore, these parameters are incorporated into semi-empirical models to generate the sound characteristic at any point in 3D due to a sound source. Different algorithms for sound models are developed in MATLAB whereas TerraScan is used for display purpose. The ability to work with different modelling algorithms under semi-empirical approach provides an opportunity to compare functionality of different semi-empirical models and arrive at an efficient composite model.

## 1. INTRODUCTION

Prediction of sound level is important for managing noise pollution, urban planning, sound barrier designing, 3D virtual realization of sound, protection of archaeological heritage etc. Sound level in real world environment is predicted using semi-empirical commercial models (Maekawa, 1968). A sound model takes various inputs, viz. location of source and receiver; location, shape and size of barriers; ground topography; location, type and size of vegetation; nature of ground between source and receiver; metrological conditions etc. Empirical techniques used inside the existing sound models suffer from approximation in algorithm as well as inadequacy in incorporating the aforesaid terrain related information (David et al., 2002; Kurze, 1973; RTA, 1989). Further, hitherto, there were also limitations in capturing accurate and dense terrain information for these models. On account of these weaknesses the existing approaches result in average sound prediction. The shortfalls of models can be overcome using high resolution 3D digital terrain information generated with laser survey (LiDAR-Light Detection and Ranging) technique. This technique can produce accurate digital terrain data of wide area in quick time. By integrating this with aerial photographs the ground can be classified accurately. Hence, LiDAR data along with aerial photographs can provide interesting opportunity to work on sound propagation modelling for better performance. Better sound prediction will benefit different related urban applications.

### 1.1 Semi-empirical Model

Semi-empirical models are essentially designed to overcome complexities of numerical models with acceptable accuracy. To simulate real world propagation of sound, these models use number of independent elements or components. It is assumed that the sound originates from source(s) and then propagates to a receiver following the principal direction of propagation. Further, while propagating the sound interacts with the

atmosphere, ground, building (barrier), tree etc. By determining the attenuation or augmentation in sound energy due to these factors the final sound energy at receiver can be computed. Different components/ elements of semi-empirical models are shown below in equation 1.

$$SPL_R = SPL_S - (DI + A_D + A_A + A_B + A_G + A_T + A_R) \quad (1)$$

Where,  $SPL_R$  and  $SPL_S$  are Sound Pressure Levels (SPL) at receiver and source, respectively.  $DI$  is the directivity index of source.  $A_D, A_A, A_B, A_G, A_T, A_R$  are attenuations due to distance, atmosphere, barrier, ground, vegetation and reflection respectively.

## 2. ALGORITHM

Different researchers/modelers have come up with different algorithms for the above elements or components. The science involved inside each of these components is discussed below.

### 2.1 Components

**2.1.1 Directivity index:** The directivity index of a source,  $DI$ , is the difference between the measured SPL in a specific direction of propagation and the level which would have been produced at that point from an omni-directional source of equal sound power. Researchers generally determine directionality of the sound source in the direction of receiver and add the corresponding contribution to sound source.

**2.1.2 Atmospheric absorption:** Small energy is absorbed in atmosphere during propagation. It occurs due to molecular relaxation and viscosity effect and is a function of frequency of sound waves.

**2.1.3 Geometric spreading/distance attenuation:** This refers to the spreading of sound energy as a result of the expansion of the wavefronts. Geometric spreading is independent of frequency and has a major effect in almost all sound propagation situations. The distance attenuation ( $A_D$ ) term is originated from Inverse Square Law.

**2.1.4 Ground attenuation:** Attenuations in SPL can occur over large distances because of interference between the ground reflected ray and the direct ray. The decrease is often most noticeable in the frequency range from 200 to 600 Hz. The attenuation produced by ground interference is related to the types of ground surface and the heights of source and receiver. ISO 9613-2 (ISO, 1996E) prescribes using three zone approach (between source and receiver) to estimate this attenuation. The CONCAWE model (Association for Information and Image Management, 1994) uses a set of ground attenuation curves to determine it, whereas ENM (RTA, 1989) model relate reflection coefficient of ground with the attenuation of sound pressure to determine ground attenuation ( $A_G$ ).

**2.1.5 Barrier attenuation:** Any building/ obstruction (having surface density greater than  $10 \text{ kg / m}^2$ ) which prevents sound rays from reaching the receiver directly is considered to be a sound barrier. In the presence of a barrier the sound can reach the receiver through diffraction. The process attenuates sound energy significantly. Maekawa (1968) came up with a simple chart using empirical technique to determine barrier attenuation. Maekawa's work guided researchers and modeler to modify, improve and develop different semi-empirical schemes to determine barrier attenuation. Different schemes (Kurze, 1973; Renzo, 2005) essentially relate attenuation with Fresnel's number which is a function of path length difference. Different techniques have been proposed to consider single building, multiple buildings, propagation over the top as well as around the sides of the buildings etc. to determine sound attenuation.

**2.1.6 Correction for vegetation and reflection:** Some of the sound energy also gets absorbed in vegetation (ISO, 1996E), especially when there is dense vegetation preventing direct transmission of sound to receiver. The vegetation attenuation ( $A_T$ ) is a function of obstructing length within vegetation and the frequency of sound wave. Presence of a reflector surface close to sound source and receiver actually alters the sound energy reaching the receiver.

**2.1.7 Weaknesses of semi-empirical models:** In semi-empirical models the parameters such as location of source and receiver, ground type data, path length difference, tree location etc are gathered from geospatial data. Generally researchers use various techniques (David et al., 2002; Defra, 2004; Kurze, 1973) to incorporate terrain related inputs to models such as (a) providing sectional profile between source and receiver, (b) contours, (c) digital terrain data (d) map digitization with approximation of building height etc. Most of these techniques cause approximate input to the model. The method of extensive survey of terrain is accurate but requires lot of man power and time. Further the algorithm/ scheme suggested by different modelers also involve approximation such as three zone approach to estimate ground attenuation (ISO, 1996E), reduction of number of buildings to reduce the diffraction complexities etc. Thus the problems that sound modeling faces currently is three pronged (1) non-availability of accurate terrain data (2) inadequate technique to feed terrain parameters into the model and (3) approximations used in sound model. These factors lead to deviations in predicted SPL compared to measured data (David et al., 2002; Kurze, 1973).

### 3. METHODOLOGY

The efficacy of LiDAR data/Aerial photo for high resolution sound propagation modeling depends on finding the technique to input terrain related parameters into models and determining a method to effectively use the available algorithms inside the models. An efficient system developed using this consideration will enable incorporating highly accurate data into the accurate model which can predict sound at any place with better accuracy. From the understanding of literature on semi-empirical modeling the important parameters such as principal path of propagation, path length difference, source to receiver distance, ground type data etc are found to be fixed for any source and receiver pair. On the other hand sound characteristic of source, meteorological conditions etc change from place to place. Hence a technique is proposed for incorporating the terrain related parameters into the model. The temporally changing parameters are planned to be fed manually. Among the spatially variant parameters the ground type data are incorporated using the aerial photo whereas the rest of the parameters are extracted from LiDAR data. At the time of determination of net attenuation of sound energy, attenuation for each component ( $A_G$ ,  $A_D$ ,  $A_A$  etc) is determined separately. Well established algorithms proposed by ISO 9613-2 (ISO, 1996E) and other modelers are used for determining different attenuation components. Instead of any vector or raster based approach, generally a point based approach is employed, which is found efficient and accurate. At the time of estimation of  $A_G$  and  $A_R$  triangulation of points between source and receiver is also carried out to determine probable points reflecting sound(s) to receiver. In the following section how LiDAR data and/or air photo are used to determine different attenuations is elucidated. In the sections 3.1 to 3.6 and the Figures 1 to 8 L stands for LiDAR point data cloud, A the air photo, P the parameter input, Pr the processes involved and AlgX the different algorithms i.e., X stands for distance (D), atmosphere (A), barrier (B), ground (G), vegetative (T) component.

#### 3.1 Distance Attenuation

LiDAR data and/or source and receiver locations can be fed to distance attenuation algorithm (AlgD) to determine distance attenuation between a pair of points (one source, one receiver) or all points in the terrain (one source, multiple receiver).

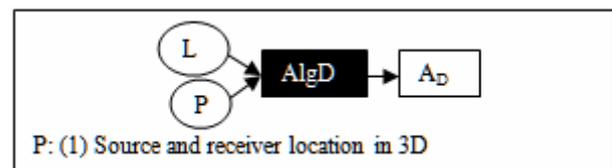


Figure 1. Computation of distance attenuation

#### 3.2 Atmospheric Attenuation

LiDAR data and/or source and receiver locations and frequency of sound wave can similarly be fed to atmospheric attenuation algorithm (AlgA) to determine the atmospheric attenuation.

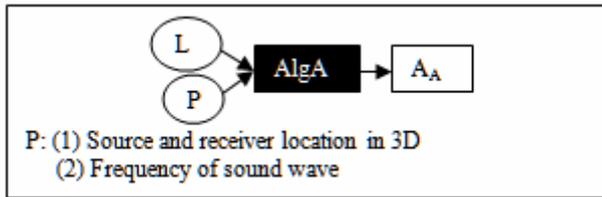


Figure 2. Computation of atmospheric attenuation

### 3.3 Barrier Attenuation

Barrier attenuation algorithm (AlgB) requires path difference due to diffraction. Sound diffraction can be possible over the top of buildings as well as around the sides of buildings. In order to obtain the path difference the building edges are extracted from the classified building data, and are used to determine the principal paths. When principal path difference(s) is/are fed into the AlgB with characteristics of sound from source it determines  $A_B$ .

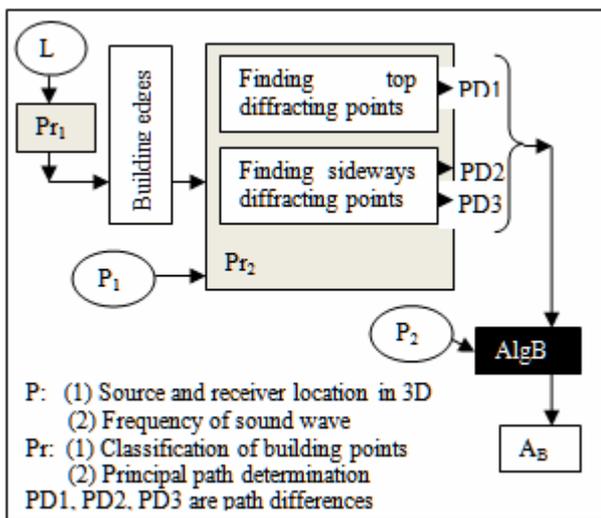


Figure 3. Computation of barrier attenuation

### 3.4 Ground Attenuation

Two different methods are attempted to determine the ground attenuation. The first determines the ground types of three zones in between source and receiver following the ISO approach.

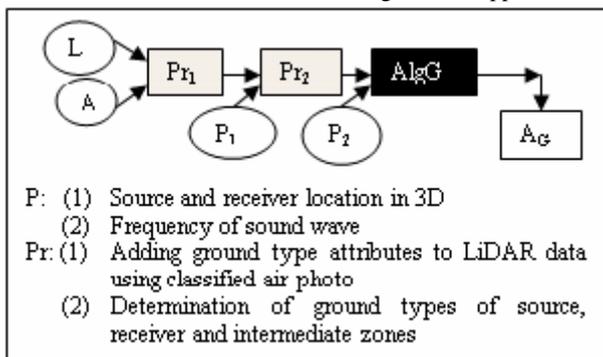


Figure 4. Computation of ground attenuation, (method 1)

The second approach determines the ground type(s) at the reflecting point considering specular reflection. When the ground type of reflection zone/point is determined it is used for ground attenuation computation. The first method averages ground types of zones between source and receiver. It is

computationally less intensive and hence fast whereas the second method tries to find points on ground which are reflecting energy to receiver. This method is appropriate for the coherent sound source.

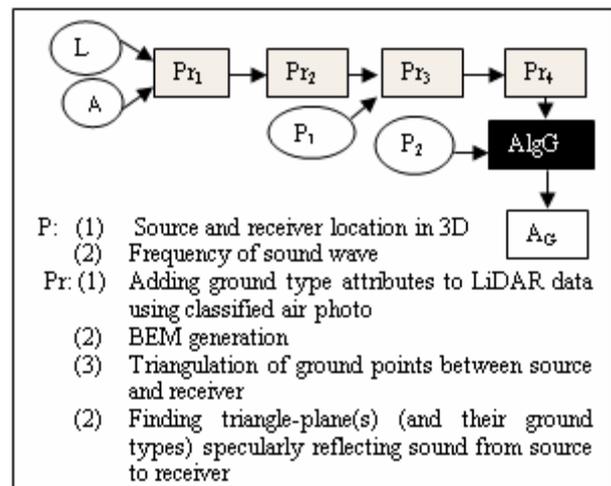


Figure 5. Computation of ground attenuation, (method 2)

### 3.5 Reflection Contribution

Reflection attenuation  $A_R$  is effectively a reflection contribution as it contributes some energy to SPL at receiver location. Reflection may be caused by walls close to source and/or receiver.

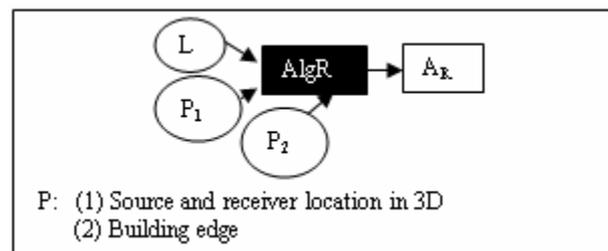


Figure 6. Computation of reflection addition (method 1)

Reflection calculation is carried out by determining those points that may result in specular reflection between source and receiver. It requires non-ground potential reflecting point classification. This is followed by triangulation of such points between source and receiver. Then the algorithm determines the triangle planes that can reflect energy to the receiver.

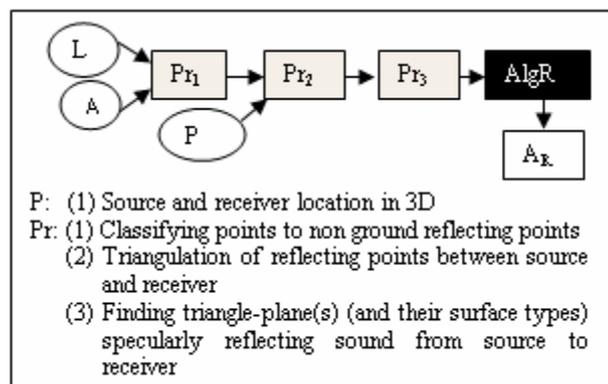


Figure 7. Computation of reflection addition (method 2)

### 3.6 Vegetative Attenuation

The attenuation due to vegetation/ tree is computed using the classified tree points. ISODATA method is employed to determine clusters of points within the point cloud of vegetation. These clusters represent individual trees or a group of trees. This is followed by triangulation of tree points corresponding to every cluster. The triangles forming the surface of clusters are used to compute the path length of sound transmission through the trees.

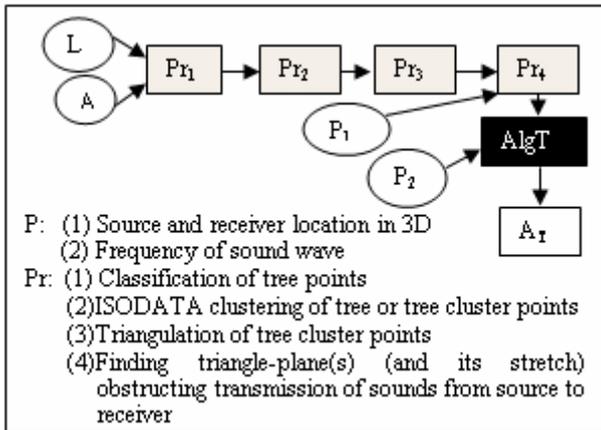


Figure 8. Computation of vegetation attenuation

## 4. DATA AND SOFTWARE USED

The purpose of this paper is to show algorithm development using LiDAR data and aerial photos. Therefore, data are chosen from different study sites and sources. The study area is primarily located inside IIT Kanpur campus. Limulator data (Limulator, 2006) of IIT Kanpur is mainly used for determination of different attenuations. Google earth image is used to assign ground type attributes to LiDAR data. It also helps in building, tree and ground point classification. Vegetative attenuation algorithm is applied over the data of vegetation areas of Niagara supplied by Optech, as the present version of Limulator does not produce data for trees. MATLAB is used for developing all algorithms. TerraScan and ERDAS are used for classifying and displaying data points.

## 5. RESULTS AND DISCUSSION

Limulator data of a small part of IIT Kanpur is employed in this paper for presentation purpose. In Figure 9, the data points are coloured by elevation. Two building (8-10 m high) (red coloured) and ground (blue in colour) are visible in plan view. A sound of 120 dB that can produce different frequencies is located at right bottom of the area. All the attenuations are shown in following figures in plan view. However, as the LiDAR data has 3D terrain information, the SPL can also be showed in 3D.

### 5.1 Distance Attenuation and Atmospheric Attenuation

SPL due to distance attenuation ( $A_D$ ) is observed (Figure 10) within a range 22 to 102 dB. SPL reduces from source following inverse square law i.e. lower attenuation closer to source and higher at larger distances. Distance attenuation is highest among all attenuations.

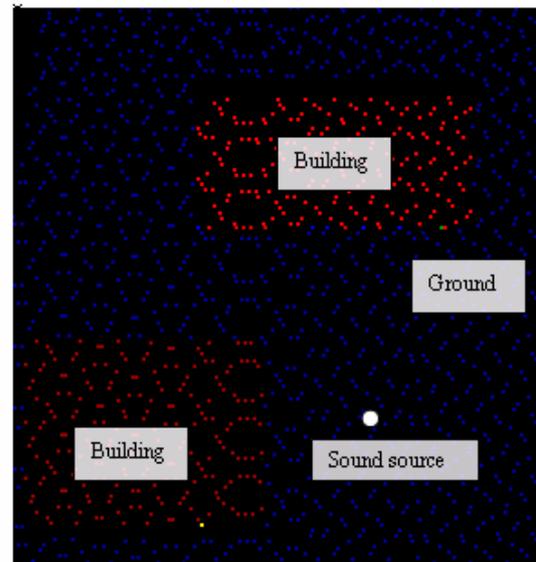


Figure 9. Study area showing building (in red) and ground (in blue)

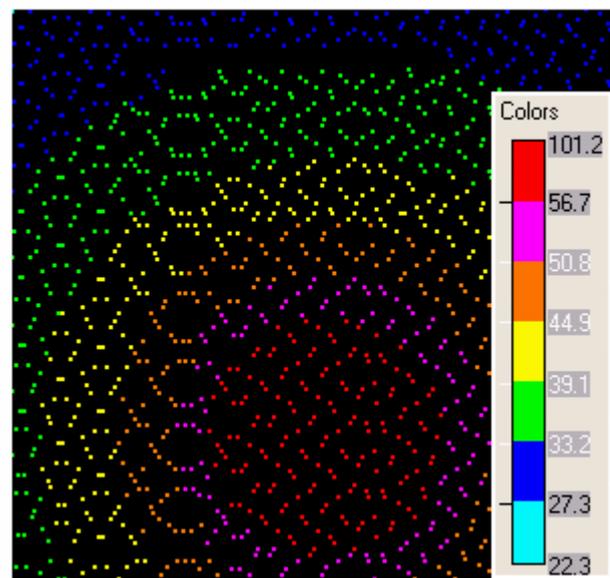


Figure 10. SPL (in dB) at different locations due to distance attenuation

Near neutral environmental conditions are considered for modelling purpose. Atmospheric attenuation varies uniformly for different frequencies. Small variation in attenuation is observed across the terrain similar to distance attenuation. However, the magnitude of atmospheric attenuation is found to be within 2 dB.

### 5.2 Barrier Attenuation

Barrier attenuation is calculated considering principal paths of sound propagation above the top and around the sides of a building as shown in Figure 11. The program developed generates an array of vertices of buildings for each principal path of propagation.

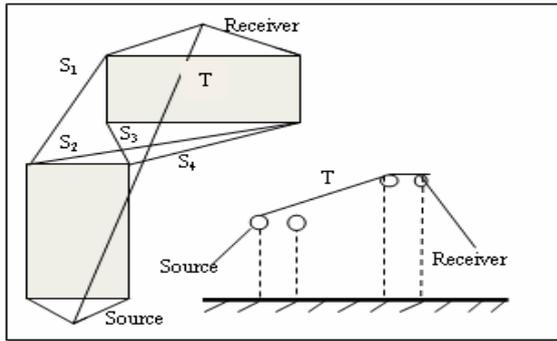


Figure 11. Principal paths. T is the diffraction over top and  $S_1, S_2, S_3, S_4$  are diffraction routes around sides of buildings

Diffraction pattern is clearly visible in Figure 12. The Places close to the source where the sound energy is not obstructed at all, do not show any attenuation (red coloured points i.e. 120 dB). The points behind the building are showing significant attenuation due to diffraction (in sky blue colour i.e. 68 to 95 dB), as expected. Barrier attenuation is dependent on the frequency of sound and constitutes the 2<sup>nd</sup> largest attenuation after the distance attenuation.

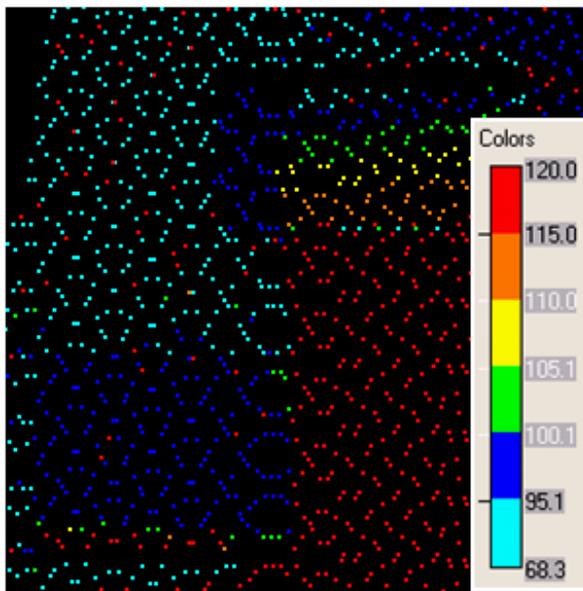


Figure 12. SPL (in dB) at different locations after diffraction attenuation

### 5.3 Distance and Barrier Attenuation

Attenuation due to the distance and barrier combined together constitutes about 90% of total attenuation. Hence the general trend of expected SPL at different locations of terrain is determined by combining both and is presented in Figure 13. In real world environment the SPL also depends on the attenuation due to ground, reflection and vegetation effects which are accounted individually, as described below.

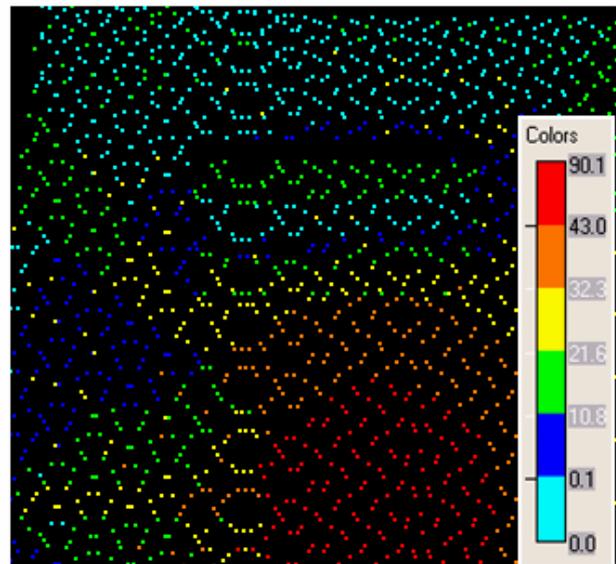


Figure 13. SPL (in dB) at different locations after distance and diffraction attenuation

### 5.4 Ground Attenuation

Ground attenuation  $A_G$  is a function of frequency, ground types around the source and receiver their heights. The effect of ground attenuation is observed at different frequencies. Figure 14 displays attenuation at 125 Hz. Ground attenuation is of order of 2.5 dB. However, it is clearly visible that it varies with ground types i.e., lower at hard grounds (building, concrete) and higher at soft grounds (grass, vegetation).

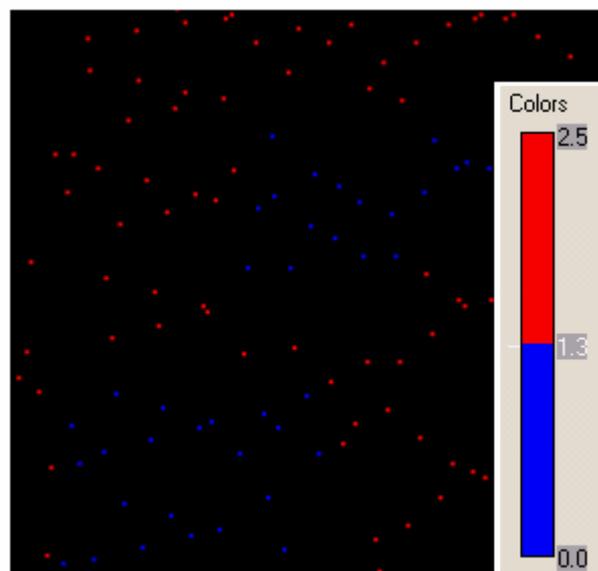


Figure 14. Ground attenuation at 125Hz

### 5.5 Reflection Contribution

The points that may cause reflection are determined and are shown as white points in Figure 15. It is apparent from Figure that points closer to two building are expected to reflect sounds to receiver unlike the rest of the points (shown in grey colour).

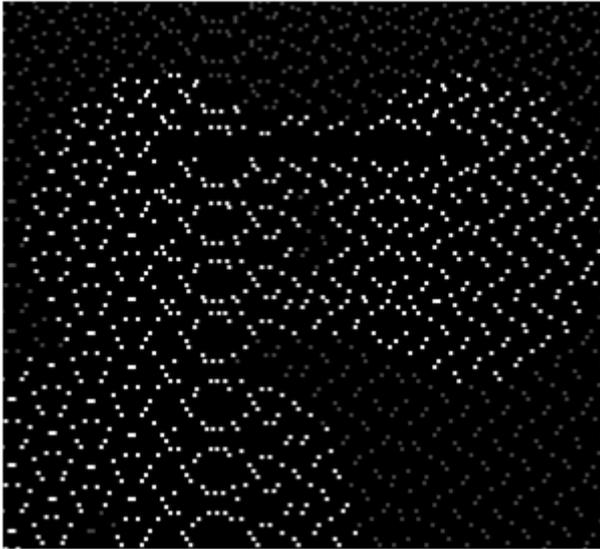


Figure 15. Binary plot of probable reflecting (white) and non reflecting (grey) points

### 5.6 Vegetative Attenuation

The LiDAR data of Niagara area are classified into the tree points class, which then are used for assessing the vegetative attenuation. 10 clusters of tree points were found between a hypothetical sound source and the receiver kept 112 m apart. The path length of sound through trees was computed as 70 m. This transmission through trees causes an attenuation of the order of few dB at different frequencies. Tetrahedral mesh of one of the clusters is displayed in Figure 16.

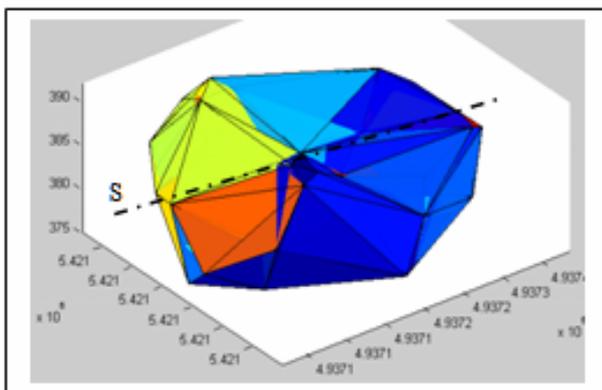


Figure 16. Tetrahedral mesh plot of a tree points cluster. S indicates location of sound source

A simplified approach for clustering could be to work in 2D with X and Y coordinates of points. Furthermore, as the attenuation due to the vegetation is small a small error in vegetation representation is permissible. This can simplify the system by fitting approximate shapes on the clusters and using these for within tree path computation.

## 6. CONCLUSION

The proposed technique of sound modelling with LiDAR data and air photo can eliminate the problems of inaccurate data acquisition and approximate parameter input to semi-empirical

model. Conventional approach of manual input of building, ground type, vegetation, reflector location etc can be totally replaced by automated, fast, and accurate LiDAR/Air Photo based technique, as presented in this paper. Precise knowledge of X,Y,Z position and dimension of different features enables the determination of sound quality at any 3D location due to a sound source with better accuracy. Approximations considered in determination of the principal paths of sound propagation between the source and the receiver is eliminated in developed approach. Principal path determination in the complex real world environment (such as multiple buildings at various orientation and of different elevation) is now simplified. Approximation in estimating ground type data in between the sound source and the receiver is improved in the present approach, where ground type of every individual point is assigned from the classified air photo and subsequently used for zone-based or point-based ground attenuation algorithm. Similarly, accurate determination of the potential reflecting points helps in reducing the reflection uncertainties. The proposed approach of vegetative attenuation determination eliminates the inaccurate and cumbersome manual approach. Further work would address the issue of efficiency of developed model, with the help of field experiments and better coding.

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