

The Genetic Algorithms for The Optimization of Distributed Loudspeaker Systems

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Summary: In some large enclosures, such as underground stations or factory halls, which involve long reverberation time, low signal-to-noise ratio, public address systems are often used to improve the speech intelligibility. Nevertheless, too many distributed loudspeaker systems suffer an inappropriate use of loudspeakers. This can lead to an imperfect uniformity of audience coverage decreasing the speech intelligibility. The use of ray tracing method associated with genetic algorithms is presented as a promising tool for the optimization of positioning and for the definition of loudspeaker number in a given room. Thus, this combination can help the designer in the conception of public address systems. The validity of this approach is illustrated in the case of choosing a best configuration from 15 possible loudspeaker locations in classroom in order to obtain an optimum speech intelligibility and to allow a smaller cost of renovation.

INTRODUCTION

The first goal of a public address system is to deliver an audible announcement. In this case, the speech intelligibility becomes the primary criterion upon which the quality of loudspeaker systems is judged. Thus, the installation of public address system should be based on achieving the highest possible degree of speech intelligibility for all listeners in a room. It requires a knowledge and an understanding of the acoustic environment in which loudspeakers are used as well as their radiation characteristics. But it is also necessary to know the acoustical factors responsible for the speech intelligibility and the way in which these factors are influenced by the design of the room as well as the interaction between the room and the loudspeakers. In these conditions, many problems must be solved and in most cases, the professional sound engineers are forced to make compromise in order to achieve an adequate solution. One of the most important cause of poor intelligibility is an inappropriate use of loudspeakers (1), (2), particularly in the choice of intrinsic characteristics of source (radiation, frequency response), the number and the location of loudspeakers.

The only way which seems to be a really good design technique for audience coverage uniformity is to make an extensive field measurement to be sure of the performance of

sound systems. Generally, this procedure is not realistic due to the number of possible configurations between locations, sources and listeners in a room. Then, the use of ray tracing method with genetic algorithms is presented as a new promising tool for the optimization source locations and for the definition of optimum loudspeaker number to be used in a given room. In the present paper, the definition of basic feature of genetic algorithms for positioning problem is proposed. The optimization method has been numerically tested to find optimal loudspeaker locations in which the speech intelligibility must be maximized.

BRIEF REVIEW ON GENETIC ALGORITHMS

The original idea of genetic algorithms is to mimic natural processes of evolution. For this reason, genetic algorithms use a genetic code represented by a string of characters and the value of fitness function which must be optimized. These two parts, genetic code and fitness function form an individual. A genetic algorithm is initiated by randomly creating a set of individuals forming the first generation individual. A second generation is then created from the first one by successive application of various genetic operators (5). This procedure is repeated until to obtain the optimal solution. In the case of the loudspeaker optimization only three genetic operators have been used: selection, crossover and mutation operators.

The purpose of selection operator is to randomly choose a pair of individuals according to their objective function value. In this case, the best individuals have more chance to be selected although less fit ones still have a non-zero probability of selection. Such a non-zero probability for all individuals is necessary to maintain a high level of diversity into the next generations and to avoid premature convergence of algorithm.

Crossover consists in a recombination of two genetic codes in order to create a new individual sharing characteristics of both parents. A crossover site, which is an integer number, is randomly selected between 1 and the length of genetic code. Then, the tail of the first individual (string of characters behind the crossover site) is changed by the tail of the second one in order to create the new individual.

The mutation operator is equivalent to introduce an error in the transmission of genetic information from one generation to another. This error is necessary since it is the only mean to incorporate new information avoiding premature convergence to a local optimum. This alteration consists in randomly selected position on the genetic code of an individual and in enforcing a random value to that position. The mutation and crossover operators are applied to each individual with a probability fixed by the user.

SPECIFIC CONSTRAINT IN APPLYING GENETIC ALGORITHMS

In the application of genetic algorithms for the source location problem, the loudspeaker positions are coded by a binary coding where each possible source location is described by

an element of genetic code. Each element has a value of 0 or 1 indicating if the source is on or off. A string such as 0111 means that 3 over 4 sources were emitting the speech message in the room.

The fitness function is described by a speech intelligibility predictor based on the concept of useful/detrimental sound energy ratio (3). This model takes account of the Definition, speech and background noise levels. In addition, it is based on an estimation of phoneme speech intelligibility following "S-shape" regression law (4). The validity of this predictor is illustrated by considering several combinations of rooms (churches, classrooms, underground stations), signal-to-noise ratio (-15dB(A) to +10dB(A)) and loudspeaker systems (central system, distributed system). A total of 150 configurations has been measured. A correlation coefficient of $r=0.92$ and a quadratic error of $\sigma = 5.3\%$ between results calculated from predictive model and subjective intelligibility tests have been found. The figure 1 only plots the results of speech intelligibility scores versus U_{50} criterion for the room test used in optimization process.

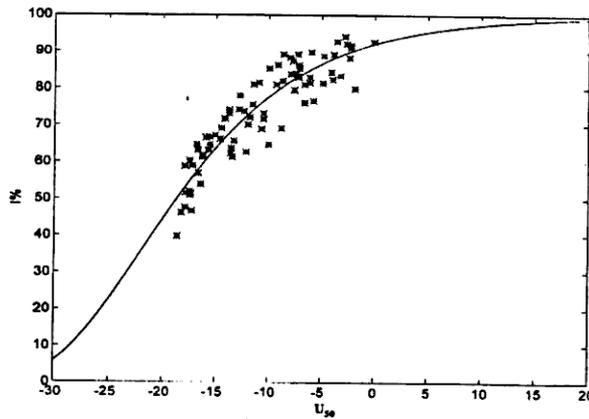


Figure 1: Intelligibility scores versus U_{50} and regression curve used in optimization process.

OPTIMIZATION PROCESS

The genetic algorithms have been used for choosing the best source locations from 15 possible positions in the classroom. This simple test is useful to evaluate the performance of the optimization method since an exhaustive search over all possible loudspeaker locations can be performed. The optimization calculation have been numerically ran with 54 microphones which uniformly situated at seated head height. The 15 loudspeakers used during the calculation were identical and presented directional properties similar to a human speaker. The stopping criteria of genetic algorithms has been chosen as a maximum number of generations to be performed. In addition, all results presented in this paper have been performed with a -8dB(A) signal-to-noise ratio. The probability of crossover and mutation have been fixed respectively at 0.7 and 0.1. From 15 possible source locations which correspond about 66000 possible combinations, the genetic algorithms find a loudspeaker arrangement which presents an intelligibility score of 60% after the evaluation of 1200 strings (figure 2).

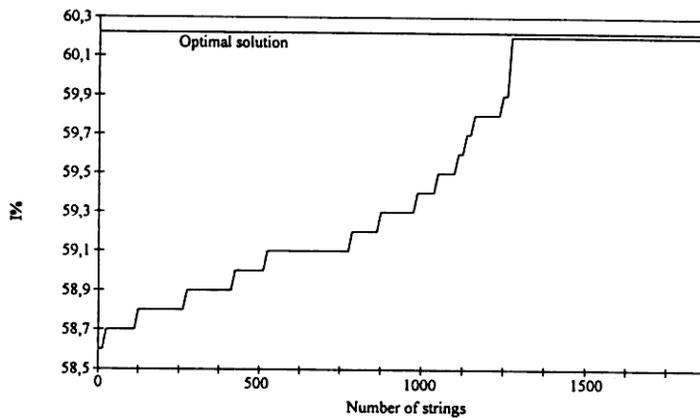


Figure 2: Genetic algorithm performance for the problem of finding an optimal solution.

This result is only 1% smaller than the best configuration found by exhaustive searching. The results indicated that the optimum solution is obtained with only 2 loudspeakers. A homogeneity criterion has been defined to control the uniformity of coverage allowing to check if the optimal solution for the speech intelligibility is also optimal for the audience coverage. This homogeneity criterion is based on the variance calculation of D_{50} values over all microphones used in the optimization process. In addition, a categorization process with simple linkage notify the user of the apparition of shadow zones.

CONCLUSION

The optimization of the source locations and the definition of loudspeaker number must lead to a good uniformity of audience coverage and speech intelligibility as well. The genetic algorithms provide an efficient and robust search process for such problems. The optimization method has found a loudspeaker arrangement which presents less 1% intelligibility score than the best configuration after the evaluating results of 1200 strings from the possible 66000 combinations. The genetic algorithms can therefore become an aid to the designer in the conception of public address systems.

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