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Optimization of control source location in a free-field active noise control application using a genetic algorithm

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ABSTRACT

By placing control sources in the near field, global attenuation of an axial cooling fan's blade passage frequency and harmonics can be achieved using active noise control. Optimization of the control source locations can be achieved by using a genetic algorithm. This paper will compare different types of genetic algorithms to achieve the optimal control source placement for a source radiating into free space. Source strengths of control sources are calculated analytically to minimize radiated sound power. The optimal configuration will be compared to control source configurations used in previous studies. Radiation characteristics of the configurations will also be discussed.

1. INTRODUCTION

Active noise control (ANC) of computer fans has become an area of increased interest in the past 10 to 15 years because of the growing need for personal computers at home and in the workplace. With computers becoming faster, and processors becoming hotter, more heat dissipation is needed. This often requires fans running at higher speeds and producing appreciable noise. Although ANC had been successfully demonstrated,[1-3] optimization of system parameters is desirable.

Achievable reduction in noise for ANC applications is physically limited by the control source configuration. Optimization of error sensor locations, reference signal, and controller will be futile if the system is limited by the control source arrangement.[4] Genetic algorithms have been used for optimization of control source and error sensor placement in a number of different active noise and vibration control applications. Martin *et al.* [5] were able to achieve attenuation of an electronic transformer by the optimization of control source locations in the near field of the primary source. Control was achieved in a free-field using discrete control source locations. Extensive work has also been done

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using genetic algorithms for control source and error sensor location placement in enclosed sound fields.[6-12] In this paper, the principles of a value-based genetic algorithm will be explored to find a control source configuration that will provide the greatest attenuation for a single primary source radiating into free space.

2. THEORY

Global free-field ANC is implemented by changing the radiation impedance of the primary source using secondary sources. In the case of fan noise, the fan is the primary noise source. Secondary or control sources are put in the near field and driven to create a mutual impedance upon the primary noise source. The mutual impedance on one source due to another source is

$$Z(kd) = \frac{jk^2\rho_o c}{4\pi}\left(\frac{e^{-jkd}}{kd}\right), \tag{1}$$

where k is the wave number, d is the distance between the two sources, ρ_o is the density of the radiation medium, c is the speed of sound in the medium. The self impedance, Z_ϕ, is found by letting $kd \rightarrow 0$ giving:

$$Re[Z_\phi] = \frac{k^2\rho_o c}{4\pi}. \tag{2}$$

The total radiation impedance of a single source becomes the sum of the self impedance and mutual impedance from each of the other sources,

$$Z_{tot} = Z_\phi + \sum_n Z_n(kd_n). \tag{3}$$

The radiation impedance "seen" by the fan will dictate the noise emission from the fan into the far field, since the radiated sound power is proportional to the real part of the radiation impedance.[14]

Source strengths for each control source can be found to minimize the radiated sound power of the entire system. The minimized sound power field will depend upon the number of control sources, the configuration of the sources, and frequency. The optimization of a control source configuration cannot be done using conventional methods because of the presence of many local optima, or configurations that are superior to all similar configurations. A genetic algorithm can be implemented to find a global optimum in a problem where many local minima exist.

3. GENETIC ALGORITHM

A. Basic Genetic Algorithm

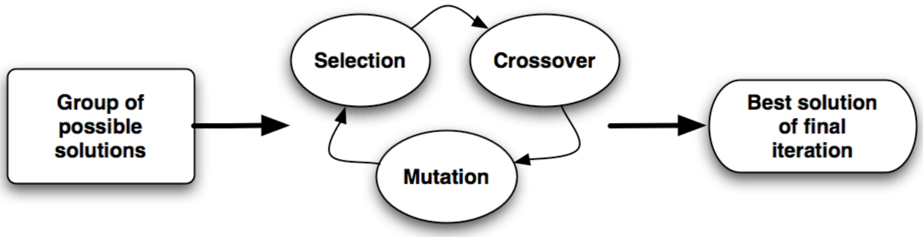

Figure 1: Flow chart of genetic algorithm

Genetic algorithms use a selection of possible solutions that are combined and changed, in a process similar to natural selection, to find the best possible solution. Configurations from the possible solutions are selected and are used to create a new group of possible solutions through a process called crossover. The new group of possible solutions is randomly changed, adding diversity into the group of possible solutions. The best configuration is chosen from the final group of configurations as the optimum. The final solution is based on probability and the type of processes used in the genetic algorithm.[13]

B. Genetic Algorithm Implementation

A value-based representation of the possible solutions was used in this algorithm. In most genetic algorithms a binary representation is used, but is limited by resolution. Each possible solution was ranked by the theoretical sound power attenuation that could be achieved. Constraints were added to the algorithm to include practical issues including source size. The algorithm will not be able to place two sources, primary or control, closer than the physical dimensions will allow. If the algorithm makes a configuration that violates these constraints, a new configuration that meets the constraints will replace the invalid solution. Each source was modeled as a single monopole at the center of a user-defined radius similar to work by Gee and Sommerfeldt.[1]

The selection process is based on probability. The configurations with better achievable attenuation have a greater probability of being used to create the new group of configurations. Typical types of crossover could not be used in this situation due to entire groups of new configurations violating constraints. A modified crossover process was developed, which we referred to as parenthogenesis. This type of crossover perturbs a single configuration based on user-defined parameters. The random changing of the group of solutions, referred to as mutation, and the crossover process were both dynamic in nature. The dynamic nature gave the beginning groups more diversity than following groups.

C. Genetic Algorithm Results

A primary source with a diameter of 90 mm was used as a representation of a 90 mm axial fan. Control sources of only 30 mm were available and thus dictated the size of the control sources used in these results. The algorithm was constrained to only two dimensions in the plane of the fan, and for work shown here, four control sources were assumed. Since the amount of control is based on the distances between the sources, a symmetric configuration (see Fig. 2) has been assumed to be the optimal configuration

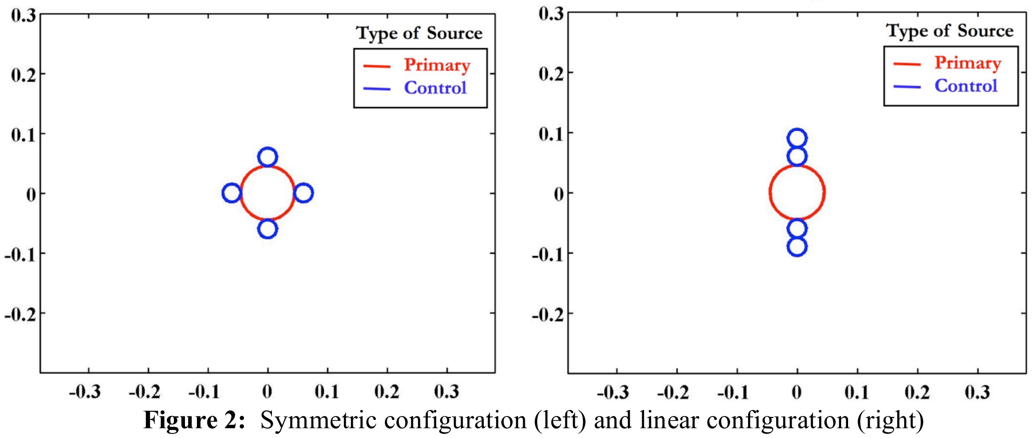

Figure 2: Symmetric configuration (left) and linear configuration (right)

based on the symmetric nature of the attenuation and the minimized distance between the primary source and each control source. However, the solution given by the genetic algorithm is not the symmetrically distributed control sources, but rather the control sources in a linear configuration (see Fig. 2). A comparison of the sound power with control, W_o, to the sound power with only primary sources, W_{pp}, from the two configurations can be seen in Fig. 3. The superior sound power attenuation from the linear configuration is not limited to a single frequency.

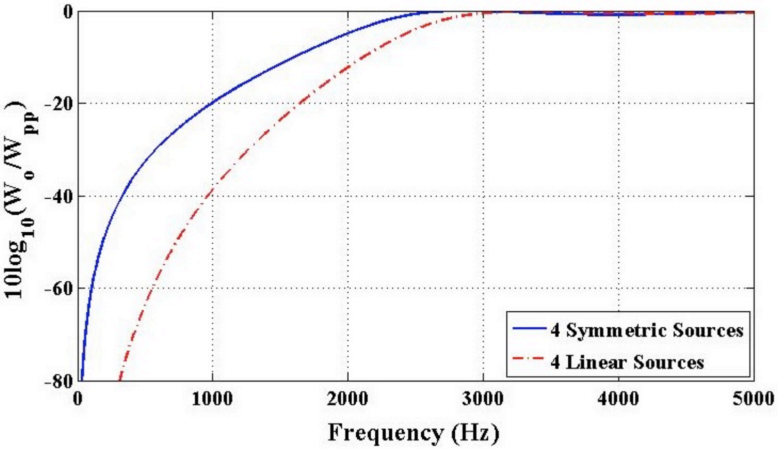

Figure 3: Comparison of sound power attenuation for symmetric and linear configurations as a function of frequency

A closer look at Fig. 3 shows that at a typical blade passage frequency (BPF) of a fan, 500 Hz, the linear configuration would be able to achieve about 30 dB more of sound power reduction (see Fig. 4). This same amount of reduction is not seen at all frequency ranges, however. At higher frequency ranges the symmetric case actually has better theoretical attenuation, but this higher frequency range has such small possible attenuation that passive noise control techniques may be more suited for the application.

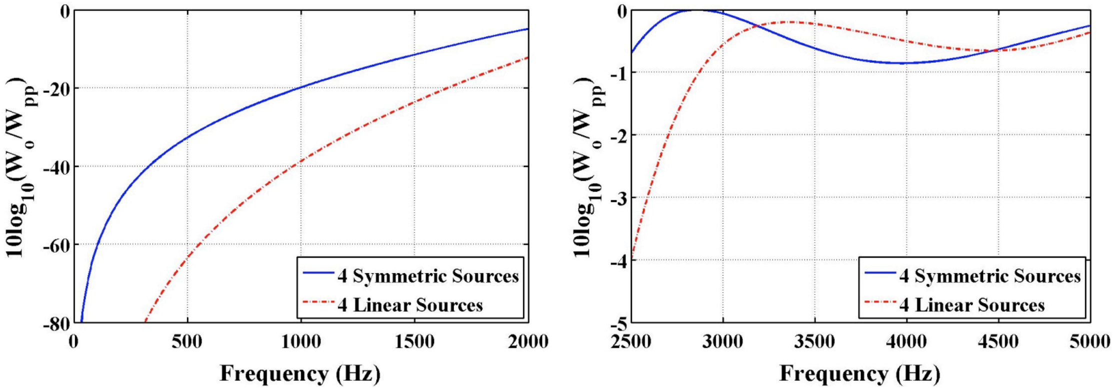

Figure 4: Zoomed plots for comparison of sound power attenuation for symmetric and linear configurations as a function of frequency

Another significant difference between the two configurations lies in the source strength required from the control sources to create the minimized sound power field. If the required source strengths are too great, the physical control sources will be unable to match the source strength of the primary source without distortion being introduced. For the symmetric configuration the source strength of the control sources, Q_s, is never required to be higher than half of the source strength of the primary source, Q_p (see Fig. 5). In the linear configuration, however, the source strength of the two sources closest to the primary source are each required to have a relative source strength between 0.65 and 0.85 of the primary source for the frequency range of interest.

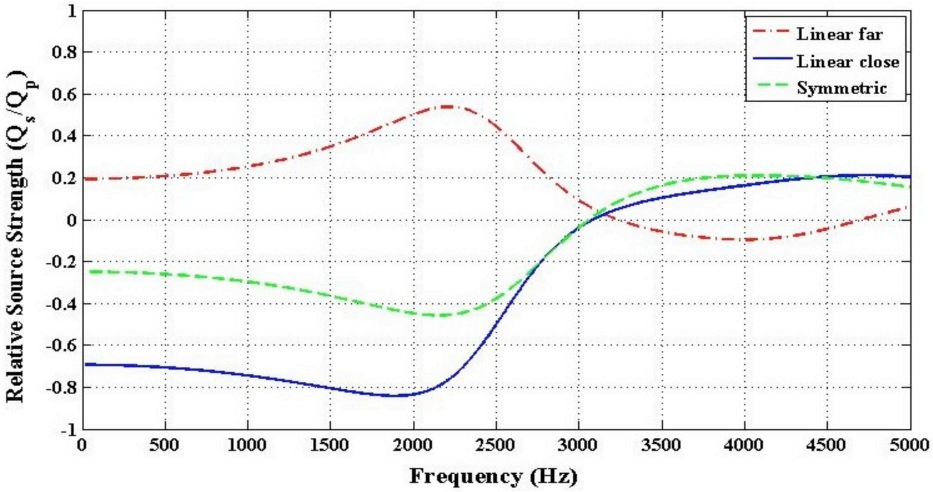

Figure 5: Relative source strengths of control sources in the linear and symmetric configurations

Allowing the algorithm to expand into a third dimension would allow for more configurations though mounting control sources may be impractical for some configurations. The algorithm would converge to two different configurations, a linear and a tetrahedral configuration, shown in Fig. 6. The linear configuration has superior sound power attenuation compared to the tetrahedral configuration as shown in Fig. 7. The tetrahedral configuration would be considered a local minimum. For the algorithm to find the linear configuration more often, a higher mutation probability and larger generations size would be necessary than was readily available for this study.

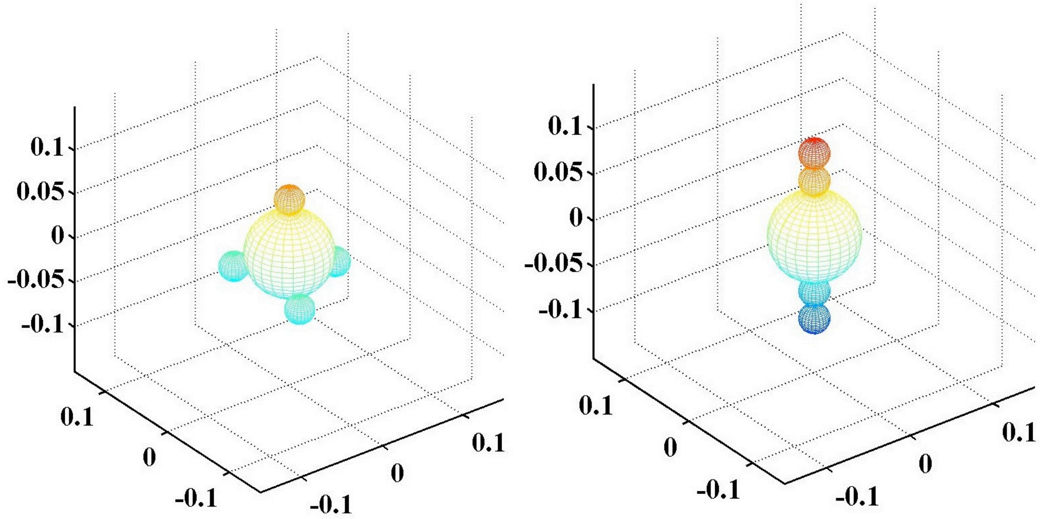

Figure 6: Tetrahedral (left) and linear (right) configurations of four control sources in three dimensions

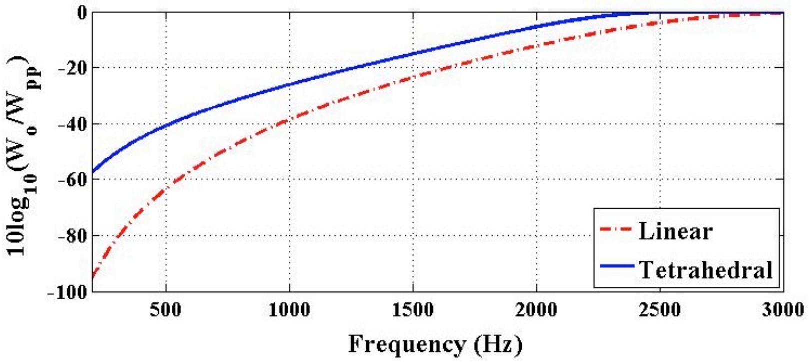

Figure 7: Comparison of sound power attenuation for tetrahedral and linear configurations

The superior attenuation achieved by the linear configuration, in both two and three dimensions, can be attributed to the smaller spacing between the control sources. If the physical size of the control sources is the same as the primary source, a characteristic distance, *d*, between sources can be used. A product of the wave number, *k*, and the characteristic distance can be used to calculate the theoretical maximum attenuation. In this case, the linear configuration achieves better sound power attenuation at lower frequencies while the tetrahedral configuration is better above a kd of 1.468 (see Fig. 8).

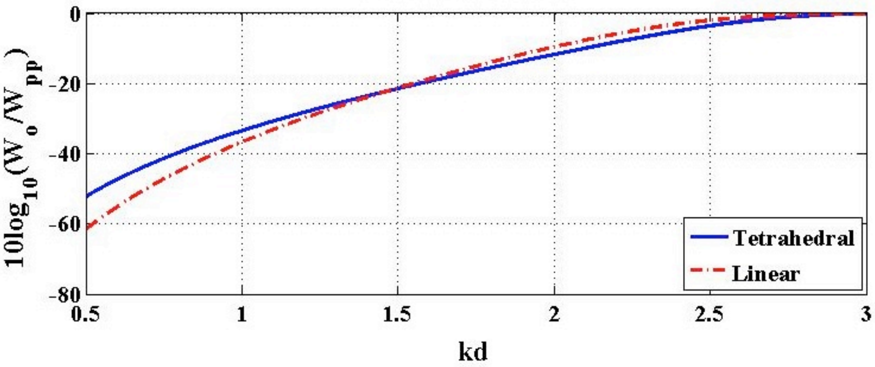

Figure 8: Comparison of sound power attenuation for tetrahedral and linear configurations using a single characteristic distance

The radiation characteristics, in the low-frequency approximation, show some significant differences. Nelson *et al.* showed that the tetrahedral configuration radiates much like an octupole, or similar to that of kd^6.[14] The linear configuration radiates as a higher order source, similar to that of kd^8. The slope of the power radiation of the two configurations in Fig. 9, on a log scale, should be similar to the slope of a power of *kd* with which it shares radiation characteristics. The higher order source radiation explains why more attenuation is achieved with the linear configuration at low frequencies, even in three dimensions.

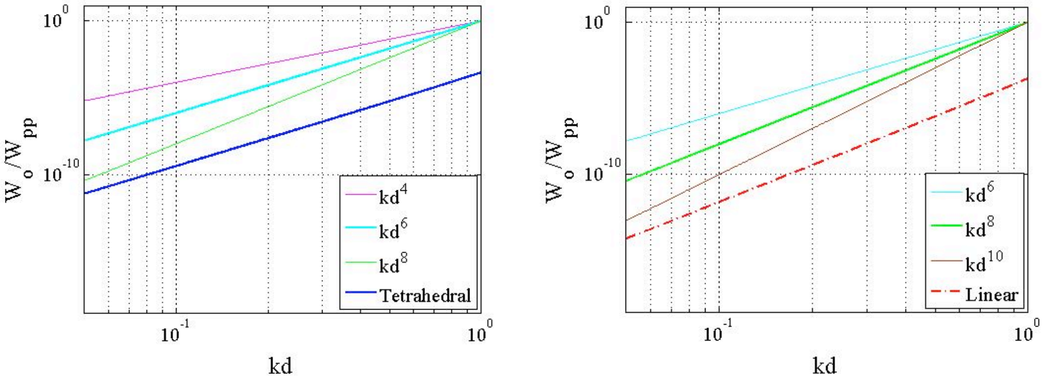

Figure 9: Sound power radiation comparison in the low frequency approximation to powers of kd for the tetrahedral (left) and the linear configuration (right)

4. CONCLUSIONS

Genetic algorithms can be used to find the optimal source configuration in active noise applications. When using four control sources and a single primary source, radiating into free space, the best sound power attenuation will be achieved by using a linear configuration rather than a symmetric configuration. Expanding the genetic algorithm to include three-dimensional configurations will also conclude that a linear configuration is superior to other configurations at low frequencies. At higher frequency ranges the tetrahedral configuration will allow more sound power attenuation when a characteristic distance is used.

5. FUTURE WORK

Further investigation is warranted into the possibility of using more than four control sources. Experimental verification is also required before this work could be practically implemented.

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