Crosstalk cancellation of virtual acoustic imaging systems for multiple listeners

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Abstract
The central aspect of the research into virtual acoustic imaging for multiple listeners involves a detailed study of the relative orientation of both sources and listeners. It is vital in any multiple listener system to first establish the conditioning of the potential geometrical arrangements of transducers and listeners. In this paper, this made clear the important link between the conditioning of the electro-acoustic transfer function matrix between transducers and ears and the design of inverse filters for crosstalk cancellation. This work has been undertaken by using simple free field models of the electro-acoustic transfer functions. Therefore, optimal transducer arrangements have been identified and these have been proved by time domain solutions.

1. Introduction
Perfect crosstalk cancellation of virtual acoustic imaging systems requires that a signal is desired at one ear of each listener and silence is sought at the other ear. The technical developments undertaken to date for a single listener, for example 2 source-2 receiver systems are described in full in references [1,2]. Meanwhile, in many practical applications, virtual acoustic imaging systems are required to design for multiple users. In such cases, the systems have to be able to create virtual environments for multiple listeners at the same time. Therefore, it is clearly necessary that researches be initiated to examine the developed techniques for the delivery of high quality virtual acoustic images to multiple listeners. In this paper, a virtual imaging system having four sources and four receivers (or equivalently two listeners) is focused. However, since this is just the start of the observation of the dependence of the condition number on geometrical factors for multiple listeners, it will be more helpful to keep matters simple in the first instance.

2. Crosstalk cancellation with a free field model for multiple listeners
For the crosstalk cancellation, inverse filters are often deduced by using the inversion of the plant matrix [1] which is defined as acoustic transmission paths between the loudspeakers and listener’s ears. In dealing with this kind of the problem, the condition number has been introduced to represent the control performance and robustness of the system [2]. The condition number of the plant matrix $\mathbf{C}$, $\gamma (\mathbf{C})$, is simply defined by $\gamma (\mathbf{C})=\|\mathbf{C}\|\|\mathbf{C}^{-1}\|$ (where $\|\|$ denotes the two-norm of the matrix)[3]. For example, in the 4 source-4 receiver system depicted in Fig.1, the receivers ($w_1$, $w_2$, $w_3$ and $w_4$) are assumed to locate in a horizontal plane. In the same plane, four monopole sources ($v_1$, $v_2$, $v_3$ and $v_4$) are aligned in

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front of the listeners. For this case, the condition numbers in dB
($= 10 \log_{10} \kappa(A)$) as a function of frequency are shown in Fig. 2.

In order to perform time domain simulations with the
geometry depicted in Fig. 1, assume that each source signal is
emitted from a Gaussian pulse specified by
\(d_{\text{source}}(t) = e^{-\alpha t^2} \cos(\omega t)\). Here \(\alpha\) is an arbitrary constant and
\(\omega_f = 2\pi f_f\) is the angular frequency. The source inputs are
designed to achieve crosstalk cancellation at the listeners' right
ears. The sampling frequency is 20480 Hz. The total sound
field is represented by nine frames which are listed sequentially
in a reading sequence from top left to bottom right. The time
increment between each frame is \(1.22 \times 10^{-3}\) second. In each
frame, the sound field is calculated at 131-by-131 discrete
points over the whole area. For each point, the transfer function
between each source and the position is calculated, and then
convolved with the source signal to obtain the acoustic pressure
at the position as a function of time. In the frames shown in Fig.
3 & 4, the results show the sound wave interference pattern in
the same horizontal plane of the sources and the receivers, and
their values greater than 1 are plotted as white, values smaller
than -1 as black. Firstly in Fig.3, the solution with the pulse in
the well-conditioned frequency \((f_o = 1275\) Hz, see Fig.2) shows
better result compared with that illustrated in Fig.4 for the pulse
in the ill-conditioned frequency \((f_o = 3740\) Hz, see Fig.2). As
shown in Fig.3, the emitted signals from the pulse with
\(f_o = 1275\) Hz vanish rapidly before reaching receivers.
However, in the case presented in Figure 4, 'ring phenomenon'
can be found, and thus the listeners must not move at all in
order to avoid any disturbance.

3. Conclusions

It has shown that, in achieving crosstalk cancellation, the
central performance of virtual acoustic imaging systems is
crucially determined by the conditioning of the plant matrix.
These examples investigated here also shown promise of
designing a specific arrangement of sources and receivers for
different frequency bands.

References

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Fig.1 An example of a configuration for the 4 source-4 receiver system

Fig.2 Condition numbers (in dB) of the plant matrix for the
configuration of the four aligned sources considered here

Fig.3 Sound field reproduced by the aligned sources at the
well-conditioned frequency band \((f_o = 1275\) Hz).

Fig.4 Sound field reproduced by the aligned sources at the
well-conditioned frequency band \((f_o = 3740\) Hz).