Chapter 5
TDOA-Based Acoustic Direction Finding

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ABSTRACT

This chapter focuses on estimating the azimuth and elevation angles of a sound emitter based on time-difference-of-arrival (TDOA) measurements using an array of acoustic sensors. The TDOA-based direction-finding problem is appropriate because in a range of scenarios the source only emits a transient signal and TDOA measurements provide a simple method of finding the direction of the received signal. Given the measurement of TDOA, three methods for calculating the actual bearing of an acoustic source are considered—algebraic calculations based on trigonometric functions, linear least squares, and nonlinear least squares—and these results are also compared with the Cramer-Rao lower bound (CRLB). In this chapter, a comprehensive analysis of TDOA-based direction-finding methods is presented with regard to different application conditions, while their estimation performances are analysed with both simulation and field experimental results produced by 3-D microphone array.

INTRODUCTION

Source localization and Direction of Arrival (DOA) estimation using sensor arrays has drawn significant attention from both academia and industry in the array signal processing field for decades. DOA estimation is usually simply called direction finding. If the source is in the far field of a receiving array, the source signal wavefront arriving at the array can be assumed to be plane wave. Then the DOA can be accurately estimated, while the range estimation error and hence position estimation error would be large especially for the high range-to-baseline ratio case. Thus multiple subarrays are needed for accurate

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position estimation. For instance, in the two-dimensional case, the crossing of bearing lines produced by two subarrays can be used to estimate the source location.

Many high resolution algorithms such as Multiple Signal Classification (MUSIC) and Estimating Signal Parameters via Rotational Invariance Techniques (ESPRIT) have been considered as the popular beamforming methods for DOA estimation. In contrast to the beamforming approach where the data are processed in the frequency domain, the Time Difference of Arrival (TDOA) based DOA estimator performs the data processing in the time domain. In the case where the acoustic signal is transient and does not have a pre-defined waveform pattern, the signal characteristics are unknown such that only the relative time delays can be measured and utilized. The azimuth and elevation can be directly calculated from the estimated time delays so that it does not need a time-consuming two dimensional search over the array manifold as the beamformer does.

The TDOA technique is one of the widely used localization schemes in cellular networks and wireless sensor networks including the use of acoustic arrays. Some indoor localization systems use ultrasonic transceivers to deliver the localization solution with a high accuracy based on the TDOA technique (Yu *et al* 2009). In a typical scenario where the source is surrounded by a number of sensors (or receivers), a single acoustic target (source) emits a signal, and the sensors detect the signal and measure the arrival time of the source signal. By calculating the signal TDOA at a number of receivers with respect to a reference receiver, the source location can be determined.

Military operations consider the accurate location of weapon system as a vital factor on the battlefield by using relative time of arrival (TOA) of the sound impulse at several accurately located microphones. The relative TOA is commonly referred to as TDOA or simply time delay. The firing of a gun or mortar generates an acoustic impulse, which propagates radially outwards from the source. The TDOA measurements by an array are used to determine the source bearing, and the battlefield target location is cross-fixed by triangulation using the bearing estimates from multiple widely separated arrays (Sallai *et al* 2011; Brian *et al* 2002).

Figure 1 illustrates the scenario where an acoustic array is employed to detect and locate the acoustic signal from a single explosion source. The sound source generates a far field signal traveling as an approximate plane wave. In the past the long baseline scheme has been used dominantly to localize a transient explosion source, because the precision of data acquisition systems was not high enough to distinguish the tiny TDOA measurements associated with small distance differences. However, the performance of the present-day equipment has been improved significantly to enable the measurement of the small TDOA values, which allows practical estimation of DOA of far field sources with a number of TDOA measurements.

Such an estimation can be realized either in the time or frequency domains. The frequency domain method involves a Fourier transform, but with this method there may be an issue related to the signal wavelength and the antenna aperture size. On the other hand, the time domain method requires a larger amount of processor memory and a higher sampling rate, and may be limited to direction finding of a single sound source. However, the time domain method has been widely applied to locate acoustic sources in many fields. For example it is especially suited for direction finding and localization of the source of a transient signal such as gunshot, cannon or bomb explosion. Furthermore, in the case where the signal is transient, the arrival difference of pulse time can be directly measured by the localization system hardware. In these scenarios, beamforming in general is not applicable since the signal characteristics are unknown; only the relative time delays can be measured. There are several techniques to estimate