A SENSOR ARRAY TESTBED FOR SOURCE TRACKING ALGORITHMS*

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ABSTRACT

This paper describes the University of Wyoming Source Tracking Array Testbed, UW STAT. This system was specifically developed to perform experimental evaluation of source tracking algorithms which use high–resolution direction finding algorithms in conjunction with an updating of the signal or the noise subspace after each snapshot. The array is a six element uniformly spaced linear array. UW STAT is a compact testbed and allows for precision source motion. The motion is controlled by a motor and the angular position is recorded by an encoder, thus allowing for a direct comparison of the tracking algorithm's performance with the true position recorded by the encoder. Initial experimental tracking results presented in the paper demonstrate the tracking performance. UW STAT information and experimental data is available on the World Wide Web at http://wwweng.uwyo.edu/electrical/array.html.

1. INTRODUCTION

In the past decade, many advanced algorithms have been developed to track moving sources using an array of sensors. Most of these algorithms rely on an updating of the signal or noise subspaces and the use of a high-resolution direction finding algorithm. Although a significant amount of research has been performed in this area, very few experimental tracking results have been reported in the open literature for actual sensor array systems [1]. In this paper, we describe the University of Wyoming Source Tracking Array Testbed (UW STAT) and give some initial experimental tracking results. Data

from UW STAT is available on the World Wide Web to researchers throughout the world. The information may be accessed at http://wwweng.uwyo.edu/electrical/array .html.

The UW STAT allows for a variety of experimental scenarios with precise control of source motion. The tracking array is a compact ultrasonic array. The compactness of the testbed and the precisely controlled environment allows for detailed studies of cause and effect. Source motion is controlled using a precision motor to turn the shaft of a radial arm. An important aspect of the system is the true source position being precisely measured using an encoder located on the shaft. Tracking algorithm performance is therefore compared to the actual position recorded by the encoder.

A few experimental sensor array systems do exist at universities. One is a full scale radar array for low-angle experiments, operated by the McMaster University Communications Systems Group. Another, similar to UW STAT, is an ultrasonic sensor array testbed [2,3] for investigating direction-finding algorithms. A third is a microphone array for speech acquisition [4,5], and the fourth is a communication antenna array [6] for experimental studies of Space-Division-Multiple-Access (SDMA) systems for wireless communications. None of these systems incorporate precisely controlled moving sources.

Many of the new tracking algorithms use high-resolution source localization methods, which estimate the direction-of-arrival of a source at one instant in time. These high-resolution algorithms are very computationally intensive because they involve the separation of the received signal into a signal subspace and a noise subspace. Much of the recent research therefore has concentrated on updating these subspaces after each snapshot of array data is received. These algorithms can usually be classified into one of two groups -- *adaptive* or *recursive*. For *adaptive* tracking algorithms the update of the subspace will asymptotically approach the true subspace if the data is wide sense stationary. For

recursive tracking algorithms the update of the exact subspace, using a new data vector, results in the exact subspace for the given modified data matrix. An excellent discussion and bibliography of many subspace tracking algorithms are given in [7]. These algorithms have been investigated with some theoretical analysis and simulation studies, but little has been reported on the experimental capabilities and limitations of the methods using actual array data.

2. EXPERIMENTAL SYSTEM

A front view of the mechanical system for UW STAT is shown in Fig. 1. The mechanical system, where signal transmission and reception take place, is contained in an echoless anechoic chamber and consists of the following: two transmitting sources capable of independent movement in the same arc about the linear receiving sensor array, a DC motor for moving one of the sources, and an encoder for precise position knowledge of the moving source. The remainder of the testbed is placed outside the anechoic chamber and consists of the following: transmission hardware, reception hardware, carrier signal generation hardware, message signal generation devices (white noise generators and arbitrary function generators), and a PC/data acquisition system.
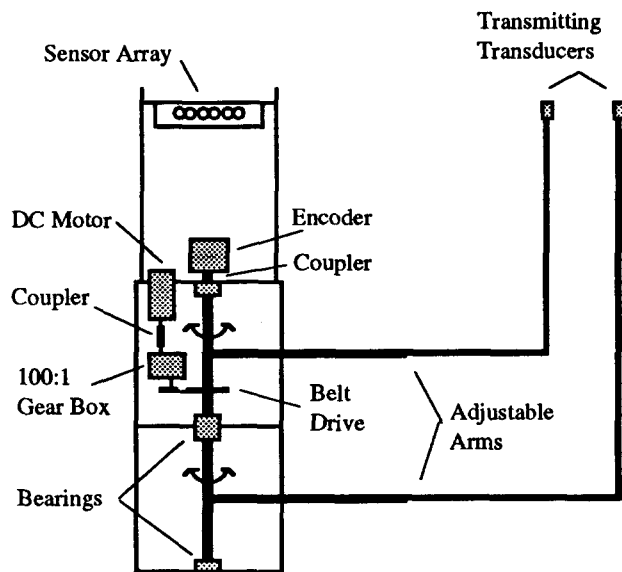

Fig. 1. Front View of Mechanical System for UW STAT

A double-sideband suppressed-carrier (DSBSC) modulated signal is generated by the transmission hardware. Message signals with an acoustic frequency range of 0 - 2 kHz from the message signal devices can be used for modulation with a carrier signal. The carrier signal is generated at a frequency of 40 kHz so that piezoelectric transducers with natural frequencies of 40 kHz can be utilized for signal transmission and reception. This ultrasonic carrier frequency allows for the physical dimensions to be practical for a testbed. The approximate narrowband plane wave generated by the transmitting transducer has a wavelength of $\lambda = 8.275$ mm. Due to the physical size of the receiving transducers, the element spacing of the linear array is 2.1λ. This sensor spacing limits the field of view for a spatially non-aliased sector from -13.5 to 13.5 degrees. This non-aliased range for the angle-of-arrival of a transmitting source corresponds well to the limited range over which the transducers can be considered omnidirectional.

Movement of one of the transmitting sources is controlled with a DC motor geared to the sources radial arm shaft as shown in Fig. 1. This allows for motion control and experimental repeatability of movement for one of the sources. In addition to the DC motor control, this source also has an incremental pulse encoder coupled to its shaft as illustrated in Fig. 1. The encoder allows for the position of the source to be known at all times as it moves through the sensor array field-of-view. Source tracking algorithm performance can be evaluated against the precisely known position of this source. The second transmitting source is able to move independently from this source at approximately the same arc length, but it does not have motor control or encoder position knowledge. This second source can be used as an interfering source to see how well source tracking algorithms perform when two sources occupying the same temporal frequency band are near each other, or it could be used to create multipath signal effects.

Signal transmission from the two sources is possible in a distance range from 1.5 m to 2.5 m. These distances support the approximate far-field plane wave assumption made in the array processing model. Gain and phase characteristics of the transmitted DSBSC signal are affected by differences in the characteristics of the six receiving transducers. The reception hardware minimizes any more perturbations in the gain and phase characteristics between the signal received at each of the sensors in the array by using a fairly insensitive design and low tolerance components. The reception hardware performs the in-phase and quadrature demodulation of the received DSBSC signal. This gives both the real and imaginary components of the message signal so that the recovered message signal information is complete. A fine-tune, variable amplifier is available at the output of

each quadrature demodulation branch to provide some slight control over temporal gain perturbations.

After quadrature demodulation of the signal received at the sensor array, a 12 bit data acquisition card is utilized to transform the recovered analog data into digital data for storage in a PC. The data acquisition system has 16 channels. Since it is desirable to sample the recovered demodulated signals from the six sensors in the array at the same time, simultaneous sample and hold circuitry is utilized in conjunction with the data acquisition card. The data acquisition card also acquires data from the encoder to allow for the precise position knowledge of one of the transmitting sources. One of the transmitted message signals may also be sampled. The digital data is then stored in the PC for processing at a later time. The array is calibrated for gain, phase, and mutual coupling errors using the method described in [3]. Thirty one measured direction vectors were used to estimate the gain, phase, and mutual coupling calibration matrix for the system.

3. EXPERIMENTAL RESULTS

The initial experiments used to investigate the performance of tracking algorithms using the UW STAT are described below. In these cases the transmitted signals are narrowband noise with a bandwidth of 200 Hz, and the snapshot rate is 800 samples per second. DeGroat's ROSANA (rank one signal average, noise average) algorithm [8] is used to update the subspaces after each new snapshot and MUSIC [9] is used to estimate the source location. The forgetting factor used in the ROSANA algorithm is set to 0.97.

In the first experiment, two approximately equal power sources are present. The signal to noise ratio is approximately six dB. One source is stationary at an angle of -3.8 degrees, while the other source is moving at a constant velocity of 0.0147 degrees per snapshot (11.76 degrees per second) starting at -10.9 degrees. Fig. 2 shows the estimated source locations as a function of the snapshot index. Also shown in Fig. 2 is the location of the stationary source and the location of the moving source as recorded by the encoder. In this case, the estimated source locations begin to lose resolution and collapse into a single source estimate when the sources cross paths. Resolution is lost when the sources come within two degrees on each other. After two degrees of separation the source locations are re-acquired.

In the second experiment, two approximately equal power sources are present. The signal to noise ratio is approximately 8 dB. One source is stationary at an angle of -5.7 degrees, while the other source is gradually accelerating. The initial velocity is 0.0120 degrees per snapshot (9.60 degrees per second). The final velocity is

0.019 degrees per snapshot (15.20 degrees per second). Fig. 3 shows the estimated source locations as a function of the snapshot index. Also shown in Fig. 3 is the location of the stationary source and the location of the
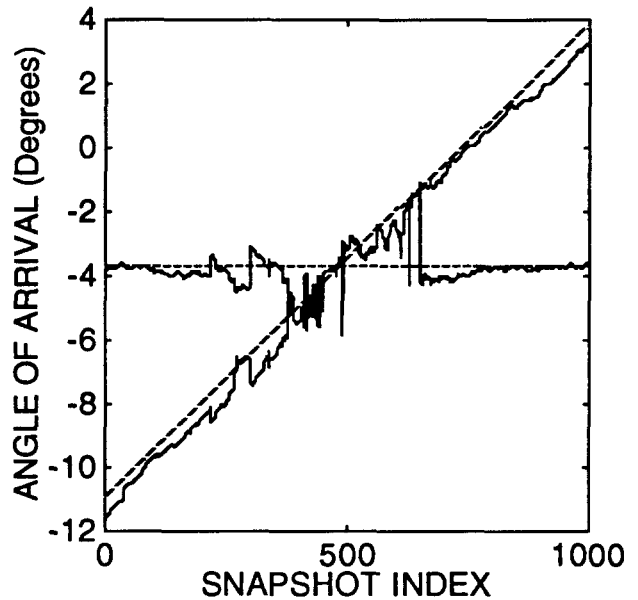

Fig. 2. Two Sources: One Stationary (-3.8°) and One Constant Velocity (dashed lines are known positions and solid lines are estimated positions from ROSANA).
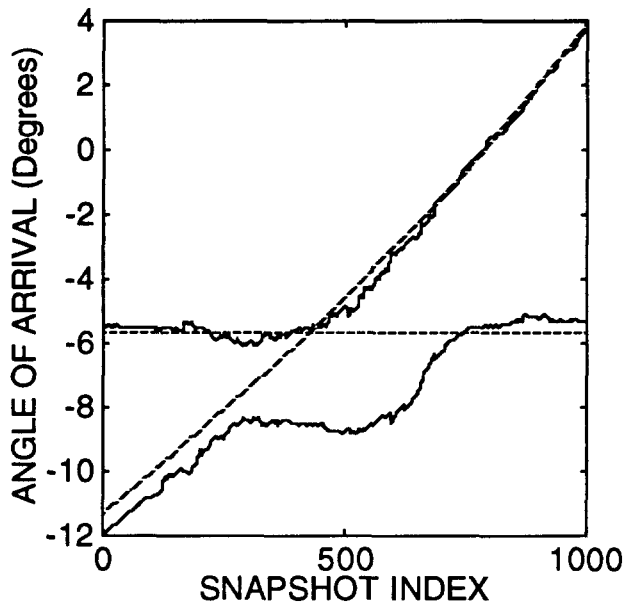

Fig. 3. Two Sources: One Stationary (-5.7°) and One Gradually Accelerating (dashed lines are known positions and solid lines are estimated positions from ROSANA).

moving source as recorded by the encoder. For this case, the location estimates of the two sources do not collapse to a single source estimate, but instead as the sources cross paths there is a significant error in one of the position estimates.

A number of data sets for a variety of experimental scenarios is available on the World Wide Web at http://wwweng.uwyo.edu/electrical/array.html. This will allow other researchers to test their tracking algorithms with data from UW STAT.

4. CONCLUSIONS

Very few experimental results, for recent advances in subspace source tracking algorithms, have been reported in the open literature. This paper describes the University of Wyoming Source Tracking Array Testbed (UW STAT) which has been developed specifically to investigate source tracking algorithms. The UW STAT provides a systematic system for the experimental evaluation of tracking algorithms which compliments previous simulation and theoretical work. The testbed maintains precise control of source position using a motor system with an encoder for measuring the true source location.

This paper described the system and gave initial experimental tracking results using the ROSANA algorithm and MUSIC. These initial tracking results were reasonable, but are only a beginning. Many other algorithms can be tested, and much more data can be collected for a variety of source movement scenarios. Future plans include the collection of additional data and continued improvements to the system.

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