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An efficient approach for improving the performance of antenna array

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ABSTRACT : *In wireless communication such as GPS, RADAR, and SPS are widely used antenna array. To analyze the Direction of Arrival (DOA) of the antenna we need a sophisticated signal processing method. This paper analyzes the antenna performance of antenna array elements by analyzing the beam pattern of an antenna array. The degradation in the detection, resolution, and estimation performance of array processing algorithms occurs due to the uncertainties of an antenna array system. In this paper, we reduced the uncertainties of an antenna array system by using the pilot calibration method.*

KEYWORDS: *Direction of Arrival, linearly constrained minimum variance, Pilot Calibration, Antenna Array, Beam Pattern*

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I. INTRODUCTION

For directionofarrival (DoA) estimation and certain smart antenna processing techniques, it is necessary to know the array manifold for all incidence angles and for array uncertainties. Array uncertainties can broadly be split into geometrical and electrical uncertainties. Geometrical uncertainties arise due to the location of the array elements and Electrical uncertainties arise as a result of the electronics of the array system due to gain, phase or frequency associated with the array elements. Antenna Array calibration is necessary to compensate for various effects, including amplitude and phase mismatch between physical antenna element hardware, amplitude and phase mismatch between element cabling, mutual coupling effects, Tower effects, imperfect knowledge of element locations and improve the performance of antenna array [1].

The two main approaches to array calibration are pilot calibration and self-calibration. In pilot calibration, sources with some known parameters are used to estimate array uncertainties analytically by exploiting the mathematical model of the array response. [2]. This paper is concerned with pilot-based array calibration in the case where there is a single pilot source available in a fixed location. Since array, shape uncertainties produce direction-dependent uncertainties, they are considered to be the most complex to estimate, requiring the most overheads and producing the largest degradation in the performance of the array system. [3]. In this paper, we analyze about the array perturbation and work on to improve the performance of beam pattern of antenna array using array calibration method (pilot calibration) to analyze the performance.

II. WORKING METHODS

Calibration by the international BIPM is the following: “operation that, under specified conditions, in a first step establishes a relation between the quantity values with measurement uncertainties provided by measurements, standards and corresponding indications with associated measurement uncertainties (of the calibrated instrument or secondary standard) and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.” This definition states that the calibration process is purely a comparison, but introduces the concept of measurement uncertainty in relating the accuracies of the device under test and the standard. [2]

During pilot calibration, sources with known parameters (i.e. known location/direction) are used to estimate the array uncertainties analytically by exploiting the mathematical model of the array response and solving a set of linear equations. For example, in [2] three or more far field pilot sources are used to estimate the complex gain, mutual coupling effects and geometrical uncertainties. Furthermore, in [4] it is shown how a single moving pilot operating in the far field of the array with a known radial velocity can be used to estimate the array shape.

We introduce linearly constrained minimum variance (LCMV) beam formers, which are widely used in acoustic array processing. The class of the LCMV beam formers is general enough to form a common framework to design beam forming algorithms for various physical setups.

Consider a time-varying multiple input, single output (MISO) system with filter coefficients $w(p)$ and output $y(p) = W^T(p)x(p)$.On LCMV beam forming, the filter coefficients are adjusted based on the statistics of the output signals. To describe these statistics, we use the expectation operator $E\{\}$ (or "ensemble average") whose argument is a stochastic process. [5]

In LCMV beam forming, the cost function is the output signal variance. Since zero-mean signals are assumed, the cost function may be defined as the output signal power of time p, that is,

$$J(p) \triangleq E\{Y^2(p)\} \dots\dots\dots\dots\dots\dots\dots\dots\dots.. (1)$$

Using the input correlation matrix,

$$R_{xx}(p) \triangleq E\{x(p)X^T(p)\} \dots\dots\dots\dots\dots\dots.. (2)$$

we can rewrite J(p) in (1) as a function of $w(p)$:

$$J(p) = W^T(p)R_{xx}(p)w(p) \dots\dots\dots\dots\dots\dots (3)$$

Now, minimizing $J(p)$ may lead to $w(p) = 0$ and $y(p) = 0$ for all p. In LCMV beam forming, this is prevented by constraining the filter coefficients linearly. For example, a simple linear constraint is that of Widrow's interference canceler where the filter $W_1(p)$ is constrained to a unit impulse:

$$W_1(p) = \delta_0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

This constraint has dimension L. More generally, a linear constraint of dimension C may be formulated with a $ML \times C$ constraint matrix C and a $C \times 1$ response vector c as

$$C^T w(p) = c \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

We find the constraint in (4) by setting

$$C^T = [I_{L\times L} 0_{L\times L}], c = \delta_0 \dots\dots\dots\dots\dots\dots . (6)$$

Note that time-varying constraints may also be considered using a time varying constraint matrix $C(p)$ and a time-varying response vector $c(p)$. For the sake of simplicity, we bound the presentation to time-invariant constraints. To summarize, LCMV beamforming consists in adjusting the filter coefficients according to the following constrained criterion:

$$Min_{W(P)} E\{Y^2 p\} \text{ s.t. } C^T w(p) = c \dots\dots\dots (7)$$

Consider the case of an LCMV beam former designed to steer the ideal array in a direction of 10 degrees azimuth with two interferences from two known directions of -30 degrees azimuth and 70 degrees azimuth. The goal is to preserve the signal of interest while suppressing the interferences. At first generate 10K samples from the target and interferences with 30dB SNR. And then Compute LCMV beam forming weights assuming the designed array. Since the array contains unknown perturbations, beam forming weights must be computed based on the positions and the taper of the designed array.

The calibration follows the approaches:

1) The pilot sources need to be chosen at different directions.
2) The number of pilot sources determines how many uncertainties in the algorithm can correct.
3) Correct both sensor location uncertainties and taper uncertainty.
4) A minimum of four external sources is required. If more sources are used, the estimation will improve.

There are several steps for this calibration technique for reducing the uncertainties of the antenna array.

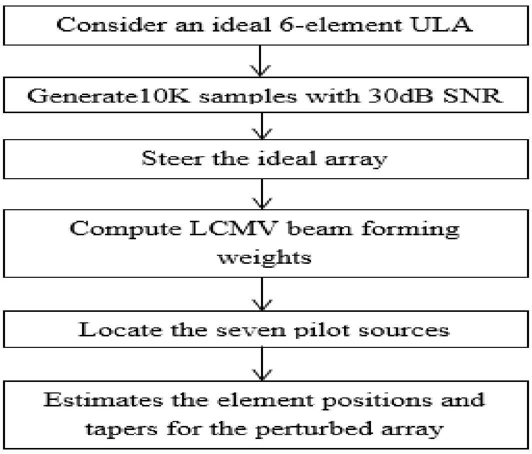

Figure 1: Steps of pilot calibration method for antenna array.

III. RESULTS AND DISCUSSION

At first, we use an ideal 6-element ULA along y-axis with half-wavelength spacing and tapering is uniform. Next, we model the perturbations that may exist in a real array. These are usually modeled as random variables. We assume that the taper's magnitude and phase are perturbed by normally distributed random variables with standard deviations of 0.1 and 0.05, respectively.

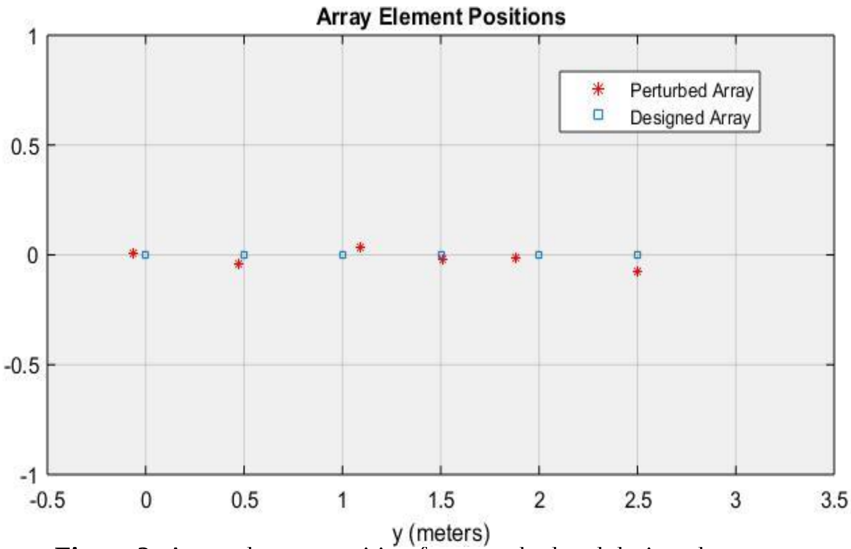

Figure 2: Array element position for perturbed and designed array.

Element array position between design array and perturbed array for six elements uniform linear array are given below:

Element Number	Designed Array Position		Perturbed Array Position	
	Position of X	Position of Y	Position of X	Position of Y
01	−0.009224	0	−0.009224	−0.06357
02	0.003664	0.5	0.003664	0.4759
03	−0.03985	1	−0.03985	1
04	−0.05428	1.5	−0.05428	1.511
05	0.03893	2	0.03893	2
06	−0.02232	2.5	−0.02232	2.497

Table 1: Array element position for $N = 6$

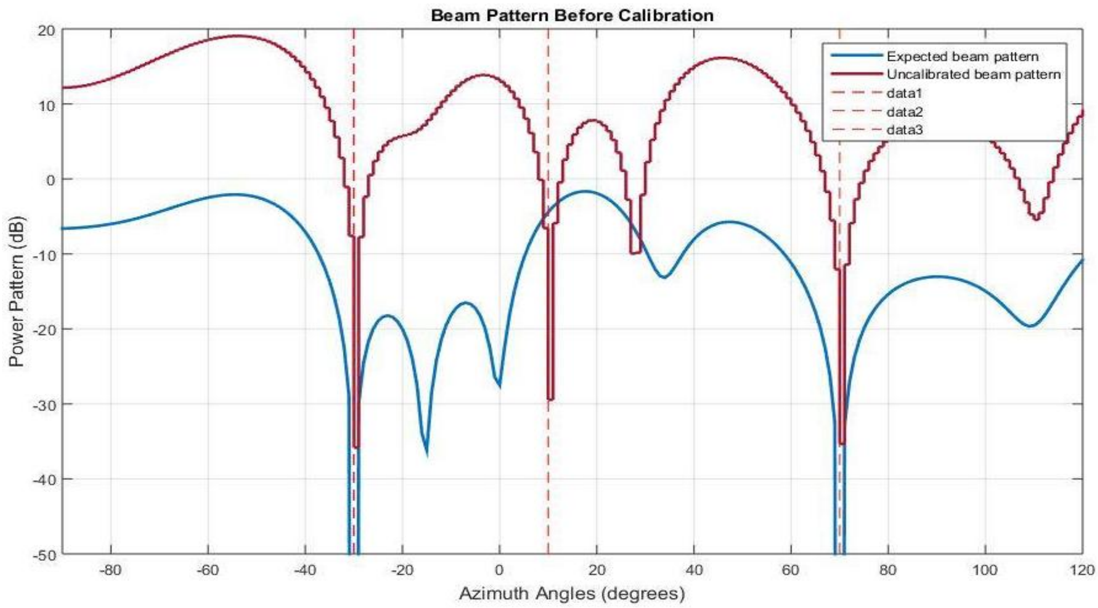

Figure 3: Beam pattern for an array of $N = 6$ element before array calibration under $SNR = 30\ dB$.

The seven pilot sources are located at the following azimuth and elevation angle pairs: $(-60,-10),(-50,-10),(-30,-5),(10,10),(-5,0),(5,0)$ and $(40,30)$. The received signal from these pilots can be simulated. Using the received signal from the pilots at the array, together with the element positions and tapers of the designed array, the calibration estimates the element positions and tapers for the perturbed array.

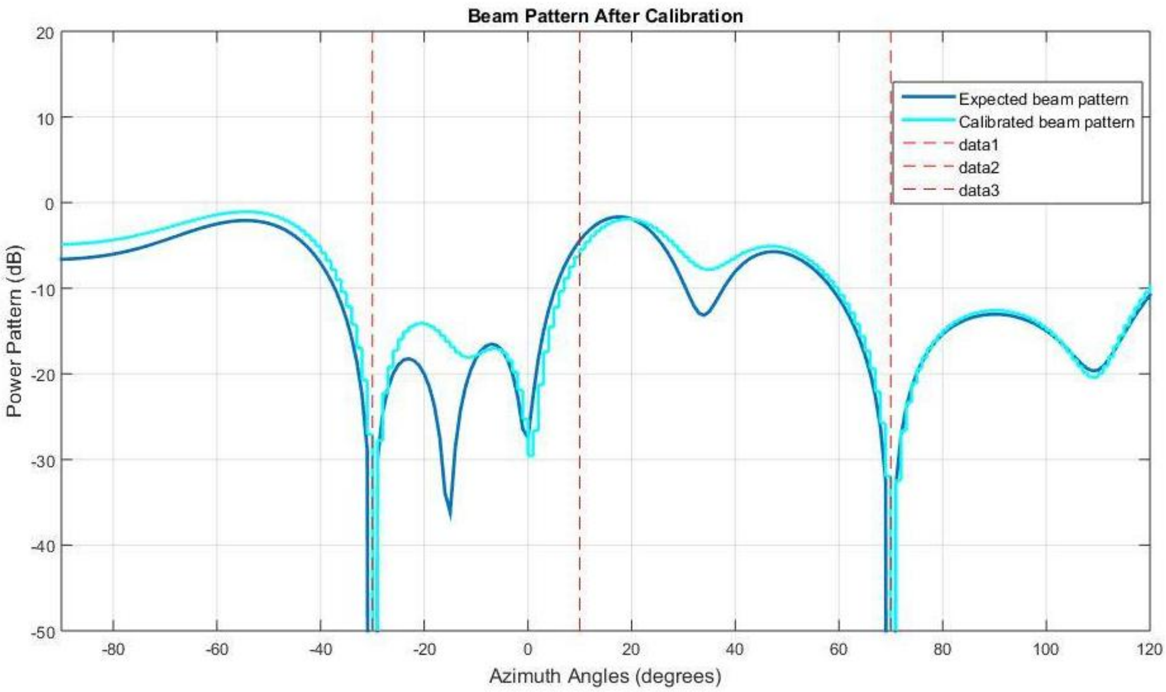

Figure 4: Beam pattern for an array of $N = 6$ element after array calibration under $SNR = 30dB$.

The figure 4 above shows that the pattern resulting from the calibrated array is much better than the one from the uncalibrated array. In particular, signals from the desired direction are now preserved. We compare the beam pattern before calibration and beam pattern after calibration with that of the pilot calibration method. The uncertainties of an array can impact its response pattern and in turn degrade the array's performance. Pilot calibration can be used to help restore the array performance of an antenna array. From the simulation we observe that before calibration the pattern of signal is far deviated from the expected signal pattern. But after the calibration of array the signal pattern is closely near to the expected pattern and signal from the desired direction are now preserved and improve the performance of an antenna array in the presence of unknown perturbations.

Azimuth Angles (Degree)	Uncalibrated Power Pattern (dB)	Calibrated Power Pattern (dB)	Expected Power Pattern (dB)
-90	12.17	-4.88	-6.627
-60	18.6	-1.366	-2.491
-40	14.19	-5.855	-7.068
-10	11.78	-17.71	-18.15
20	7.606	-1.98	-1.915
50	15.55	-5.476	-5.98
60	9.846	-10.79	-11.21
90	7.809	-12.59	-13.04
120	9.279	-9.655	-10.81

Table 2: Comparison of uncalibrated beam pattern and calibrated beam pattern with respect to expected beam pattern.

IV. CONCLUSION

In many modern wireless communication systems, antenna arrays are the key component to produce more efficient output. They are used to both increase the gain in the direction of a desired signal as well as to reject interfering signals. In this paper, we discuss about the array calibration methods to estimate array uncertainties in the antenna array system. When these arrays are implemented, a variety of practical considerations will cause the actual antenna weights to differ from the optimal weights, which in turn degrades the performance of the array. The method significantly improves the performance of an array system by removing, the array location Uncertainties. Here, we analyzed the performance of beam pattern using calibration method called pilot calibration. We use the sources with some known parameters to compensate the errors. We started it by considering an antenna array calibration system, which maximizes the improvement of beam pattern of antenna array in a desired direction. In future we wish to work on phase and amplitude error on antenna array performance. We wish to analyze the effect of uniform amplitude and phase errors, and gain of the antenna array.

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