

ADAPTIVE SNAPSHOT TECHNIQUE FOR DOA FINDER

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Abstract

Direction of arrival (DOA) estimation is an important topic for a wireless communication area. So far, the multiple signal classification (MUSIC) algorithm is the most popular one in the field of DOA estimation because it is noticeably simple but effective. However, the resolution becomes low when the number of snapshots is not appropriate for the received signal power. Therefore, this paper proposes an adaptive snapshot technique to solve the aforementioned problem. The idea is to have a DOA finder which is able to adapt the snapshot numbers according to the received power to maintain the accuracy of the DOA estimation. A DOA finder prototype is also constructed to validate the proposed idea.

Keywords: Direction finding, array antennas processing, DOA estimation, wireless communications

Introduction

Over the last decade, research related to the use of multiple antenna systems has exploded. This is because those systems have the potential of achieving high-rate data access and increased capacity of wireless communication systems. One outstanding example of multiple antenna systems is smart antenna systems (Alexiou and Haardt, 2004; Winters, 2004). The systems consist of an antenna array accompanied by a suitable signal processing unit. The beam formation is performed in such a way that the main beam is directed to the desired signal while sidelobes or nulls are pointed to the directions

of undesired signals. As a result, the overall system performance can be enhanced. So far, the use of multiple antenna systems has also gained lots of attention from researchers in the area of source identification, namely direction of arrival (DOA) finding. In a DOA finder, the signals received from individual antenna elements are passed through the signal processing unit which is utilized to perform the DOA estimation using a suitable finding algorithm. We can find effective DOA finding algorithms from the literature e.g., the multiple signal classification (MUSIC) (Hong, 2005; Bo, 2006) and the estimation of signal

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parameters via rotational invariance techniques (ESPRIT) (Roy and Kailath, 1989; Abdallah *et al.*, 2006). However, the MUSIC algorithm is the most popular one because it is not complex and it gives an accurate direction estimation. However, the performance of MUSIC is poor when the signal-to-noise ratio (SNR) is small (Zhang and Xi 2007; Ye *et al.*, 2007). Therefore, some approaches to improve the MUSIC performance have been discussed so far. One simple method to deal with this impairment is to increase the snapshot numbers (Kaveh and Barabell, 1986; Xin and Sano, 2004). However, a huge number of snapshots will introduce some drawbacks such as processing delay and the requirement of a large memory on the processor.

Therefore, this paper proposes an adaptive snapshot technique for the DOA estimation when employing the MUSIC algorithm. The proposed technique will provide an adaptation in the number of snapshots according to the received signal power. For example, the snapshot numbers will be decreased when the received signal is at the satisfied level but, when the system is facing a situation which decreases the received signal power, the snapshot numbers have to be increased. According to this, the system can estimate the direction without delay in the case of high SNR. On the other hand, when the received signal becomes low the snapshot numbers will be increased in order to maintain the accuracy of the DOA estimation.

The remainder of this paper is as follows. After this short introduction, a brief background regarding the MUSIC algorithm is shown in Section I. Next, Section II shows the framework of the hardware realization. Section III discusses the procedure of the adaptive snapshot technique and shows some experimental results of the proposed technique. Finally, Section IV concludes the paper.

Algorithm Principle

The MUSIC algorithm (Liberti and Rappaport,

1999) is adopted to estimate the DOA for this paper. This is because this algorithm is noticeably effective but not complicated, and hence is very popular in the field of DOA estimation. The DOA is determined by searching for the direction vectors $a(\phi)$ which are orthogonal to the noise subspace. The MUSIC spatial spectrum for the MUSIC algorithm can be written as:

$$P_{MUSIC}(\phi) = \frac{1}{a^H(\phi) V_n V_n^H a(\phi)} \quad (1)$$

where V_n contains the corresponding eigenvectors of the covariance matrix of the received signal, $a(\phi)$ stands for the steering vector, and H represents the conjugate transpose operation. Note that the detail of the MUSIC algorithm can be further pursued in some literature (Xin and Sano, 2004).

In (1), we utilize N isotropic antenna elements located in the x-y plane and arranged in linear form. The antenna response vector of this uniform linear array (ULA) can be expressed by

$$a(\phi) = [1, e^{-j\omega}, e^{-j2\omega}, \dots, e^{-j(M-1)\omega}] \quad (2)$$

where

$$\omega = kd \cos(\phi) \quad (3)$$

when $k = \frac{2\pi}{\lambda}$ with λ is the wavelength of the incident signal. The d denotes the inter-element spacing and ϕ is the angle of the incident signal in the azimuth.

In this paper, we present a mean square error (MSE) (Srinivas and Reddy, 1994) in the DOA estimation for the case of the ULA with an isotropic sensor and consider only 1 signal source. We also assume that a signal with power (P) is impinging on the ULA of M isotropic sensors from direction ϕ , where N is the number of snapshots performed at the received antennas. For this case, we ignore any loss of generality ($\sigma_g^2 = 0$ and $\sigma_\phi^2 = 0$ denoting the variances of the sensor gain and phase error, respectively), so that the nominal gain of each sensor is unity. The simplified

results also apply to the MUSIC algorithm. Note that the details of the MSE can be further pursued in Srinivas and Reddy (1994).

$$(MSE)_{RMU} = \left[\frac{\lambda}{2\pi \cos(\theta)} \right]^2 \times \left[\frac{12\sigma_\phi^2}{M(M^2-1)} \left(1 + \frac{1}{N} \right) + \frac{6\sigma_n^2}{M(M^2-1)PN} \left(1 + \frac{2\sigma_{sum}^2}{M} \right) \right] \quad (4)$$

where

$$\sigma_{sum}^2 = \sigma_g^2 + \sigma_\phi^2 \quad (5)$$

Figures 1 and 2 demonstrate the root mean square error (RMSE) values obtained from the computer simulation and the prototype, respectively, employing the calculation which appeared in (4). For the case of the ULA, 4

antenna elements are equally spaced by half-wavelength. Also, we assume that the signal is coming from 30° off the boresight direction. The snapshot numbers are assumed to be 10, 30, 50, and 100 when performing the MUSIC algorithm and the procedure is repeated 50 times. In these 2 Figures, the SNR is varied from 0 to 50 dB. As we can see, when the SNR or signal power increase, the RMSE of each snapshot (or estimation error) is reduced for both the simulation and the experiment. This confirms that an increase in the snapshot numbers gives rise to accuracy in the DOA estimation.

Implementation of the DOA Finder

The block diagram of the DOA finder prototype (Fredrick *et al.*, 2002; Jeon *et al.*,

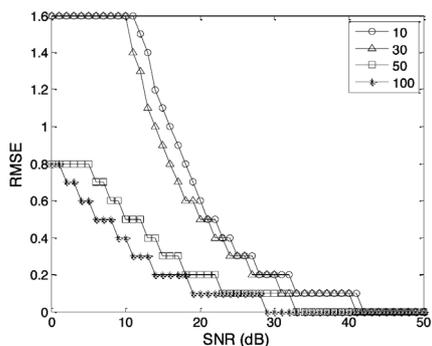


Figure 1. RMSE of DOA finder versus SNR when 1 signal is coming from 30°, from simulation

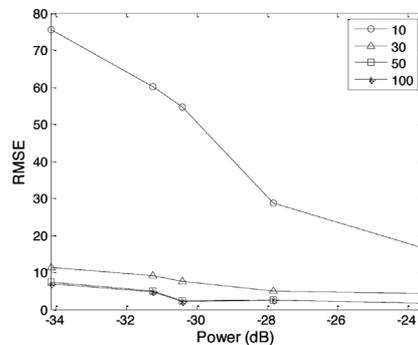


Figure 2. RMSE of DOA finder versus signal power when 1 signal is coming from 30°, from experiment

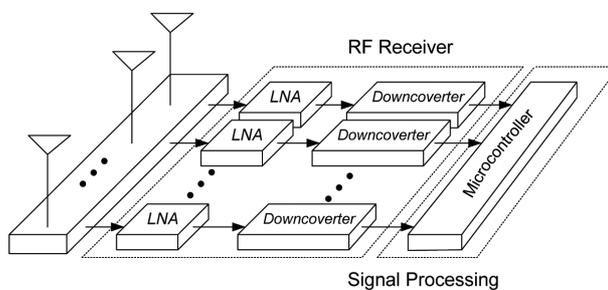


Figure 3. Block diagram of the DOA finder prototype

2002) is shown in Figure 3 and consists of 3 major parts: array antennas, radio frequency (RF) receiver, and signal processing units. The monopole antenna is used as the antenna element receiving the signal at 2.45 GHz. The RF signal received from the antenna array is amplified and down-converted to an intermediate frequency (IF) signal at 50 Hz in part of the RF receiver. The RF receiver includes a low-noise amplifier (LNA) and a down-converter circuit. Finally, a microcontroller converts the IF signal from analog to digital which is sent to the computer for data collection. The received signal will be off-line processed using an own-developed Matlab programming. Note that we utilize a finite impulse response filter to strain the digital signals before taking them to estimate the direction of the incoming signal.

The setup of the DOA finder using the MUSIC algorithm is shown in Figure 4. Figures 5 to 8 show the scenarios in direction estimation for 2 examples. In Figure 5, the signal is coming from 70°, whereas the signal

is coming from 120° in Figure 7. In these cases, we use the ULA with 4 antenna elements equally spaced by $\lambda/2$ and the number of snapshots is 100.

Figure 6 shows the received signal and power spectrum when the signal is coming from 70°. As we can see, the obtained results reveal the accurate direction estimation. Furthermore, when we change the incoming direction to 120°, the obtained estimation is still correct. Therefore, the experimental results confirm that the DOA finder can work very well in real circumstances.

Figure 9 shows the scenarios for DOA finding when varying the incoming direction from 0° to 180° and the snapshot numbers of 10, 30, 50, and 100, respectively. The obtained results of the RMSE for the worst case from the scenarios shown in Figure 9 are shown in Figure 10. This procedure was repeated 50 times for each number of snapshots. As expected, the accuracy of direction estimation increases when the received power increases for every number of snapshots.

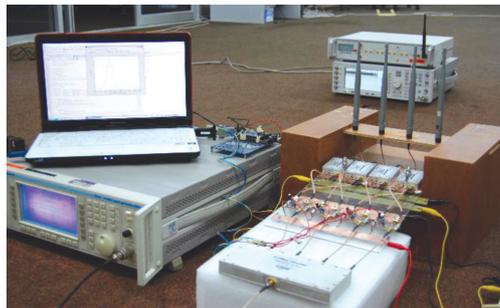


Figure 4. Setup of the DOA finding experiment

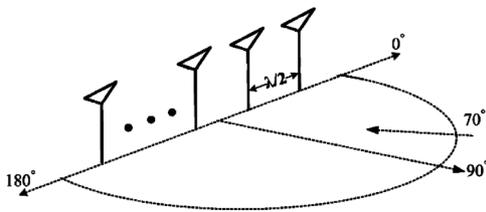


Figure 5. Scenarios for DOA finder employing linear array antenna when 1 signal is coming from 70°

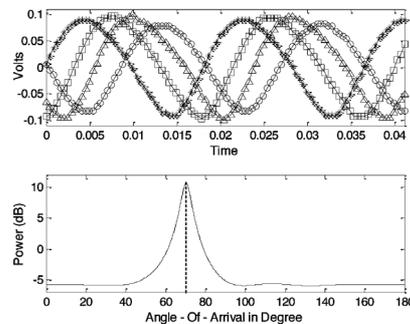


Figure 6. Received signal and MUSIC spectrum when 1 signal is coming from 70°

Adaptive Snapshot Technique

As seen from the previous section, the direction estimation accuracy strongly depends on the number of snapshots collected at the antennas.

Moreover, it also depends on the system's SNR or the received power. So far, a large number of snapshots are fixed to guarantee the system's quality regardless of the level of the SNR. As a result, a huge part of the memory

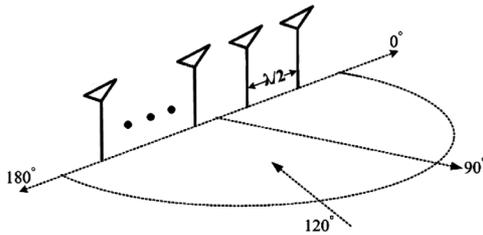


Figure 7. Scenarios for DOA finder employing linear array antenna when 1 signal is coming from 120°

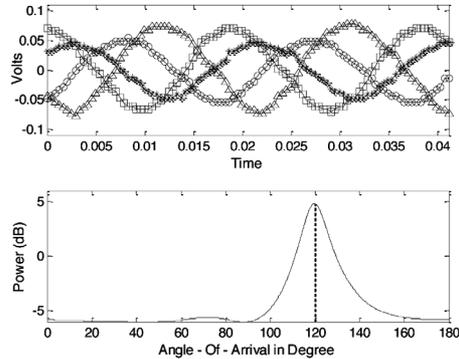


Figure 8. Received signal and MUSIC spectrum when 1 signal is coming from 120°

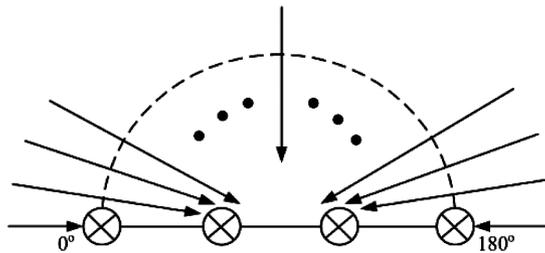


Figure 9. Scenarios for DOA finding when varying the incoming direction from 0° to 180°

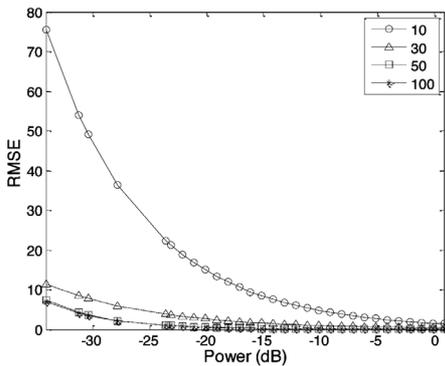


Figure 10. RMSE of worst case scenario when varying direction from 0° to 180° and snapshot numbers for 10, 30, 50, and 100

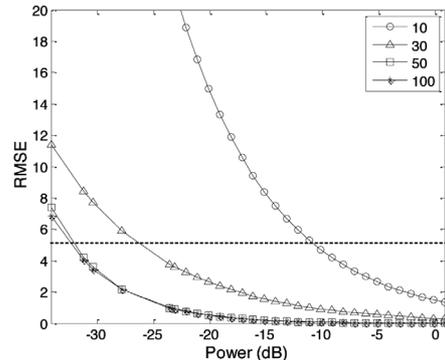


Figure 11. RMSE of worst case scenario expanded from Figure 10 and the error value set at not larger than 5

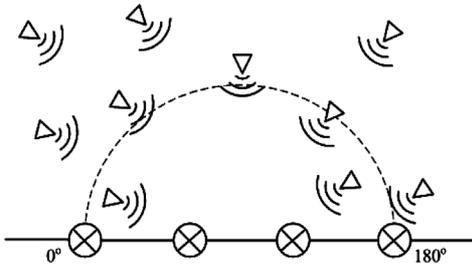


Figure 12. Scenarios for DOA finding when 10 signals are coming from different directions and distances

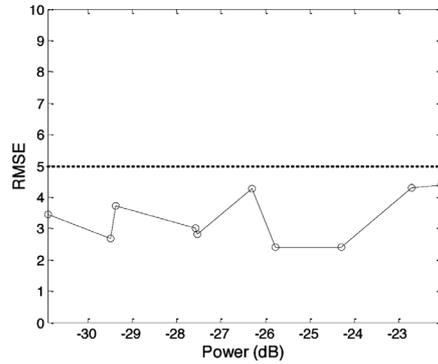


Figure 13. RMSE of DOA estimation with error threshold at 5

Table 1. The conditions for adaptive snapshot technique which set the error value at not over 5

Power (dB)	Number of snapshots
$\leq (-31.350)$	100
$(-31.350) - (-25.715)$	50
$(-25.715) - (-10.660)$	30
$(-10.660) - (0.842)$	10

Table 2. The results of adaptive snapshot numbers for scenarios in Figure 12

DOA of signal (degree)	Distance (m)	Number of snapshots
15	1	30
35	3	50
60	2	30
60	5	100
70	4	50
90	3	30
120	2	30
120	4	50
130	1	30
160	1	30

of the processor is unnecessarily occupied and also the time delay is more pronounced.

In this section, we introduce the adaptive snapshot technique from considering the RMSE of the worst case scenario shown in

Figure 10. First of all, the error threshold has to be set up. This threshold level depends on the satisfaction of the designer. A lower threshold comes with higher accuracy. However, higher accuracy means a heavy duty

load for the processor. For example, we set the threshold level at 5, as shown in Figure 11. This means that the system adapts itself to find the suitable snapshot numbers to limit the estimation error to be not higher than 5. The outcome of the adaptive snapshot, depending on the received power, is shown in Table 1. As we can see, the system unburdens itself when the received power is high (a higher SNR). For some reason, the system also maintains the accuracy of the DOA estimation when the received power is lower.

Figure 12 shows the scenarios for the DOA finder employing the MUSIC algorithm when having 10 signals coming from different directions. Note that these 10 signals are also coming from different distances. The obtained results of the DOA estimation with the error threshold at 5 are shown in Table 2. As we can see, a low number of snapshots are required when the signal source is nearby the finder. On the other hand, the finder has to increase the number of snapshots when the received signal is weak as it is coming from a long distance.

Figure 13 shows the RMSE of the DOA estimation for the conditions shown in Table 2. It is apparent that the estimation error is not larger than 5 for all the cases of received power. This is because we initially set the error threshold at 5.

Conclusions

This paper has proposed the adaptive snapshot technique to estimate the direction of the incoming signal when employing the MUSIC algorithm. A prototype of the DOA finder has been constructed to validate the proposed idea. Also, the obtained results confirm that the proposed adaptive snapshot unburdens the processor when facing high levels of received power. Also, for some cases, when the system receives low signal power, it can find a suitable number of snapshots in order to maintain the system's quality. The proposed idea helps to save processing memory and also decreases processing delay.

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