REDUCTION OF SIDELOBE ARTIFACTS AND SPECKLE IN MICROWAVE IMAGERY*

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INTRODUCTION

An antenna array large enough to provide high angular resolution imaging at microwave wavelengths will be thinned by several orders of magnitude, for otherwise the cost would be excessive. For example, the exposed area of the human eye in bright sunlight is about $10^7\lambda^2$. A camera lens under the same conditions is about $10^8\lambda^2$, while a 2 in optical telescope, large enough to provide 1,000 line resolution on the moon, is about $10^{10}\lambda^2$. It is evident that phased arrays large enough to provide the resolving power of these instruments will have a mean element spacing of thousands of wavelengths.

TWO PROBLEMS

While such drastic thinning suitably limits the cost, it also ensures a horrendous sidelobe problem. Huge sidelobes introduce two types of artifacts into a microwave image: False targets appear as sidelobe responses of the imaging system to scatterers having large radar cross sections, and speckle breaks up the images of targets of large size into smaller target images. Both problems are significantly alleviated by the technique described in this paper, which is based upon an image processing method introduced nearly a decade ago in multiple element interferometry in radio astronomy. Called CLEAN, this procedure successively removes large targets and their sidelobe responses by subtracting the point spread function of the receiving system centered at the locations of the bright targets. CLEAN was designed for noncoherent radiation fields derived from independently-radiated point sources such as stars.

This paper extends the concept to coherent radiation fields due, for example, to target echoes from radar or sonar transmitters. The theory is put on a rigorous basis, and includes the effects of noise and random errors in the locations of the antenna elements.

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SIDELOBES AND SPECKLE

It is well known that grating lobes, resulting from periodicities within a thinned array, produce multiple repetitions of an image. Although grating lobes can be destroyed by randomizing the element positions, the high sidelobes of the random array introduce undesirable image artifacts.

The speckle problem results from the coherent nature of the microwave radiation. Coherent destructive interference in the sidelobe responses of strong scatterers within a target can cause the image of the target to break into small pieces. Such a target would appear as several smaller targets.

The coherent CLEAN procedure addresses both problems. The image artifacts due to the high sidelobes of the random array are eliminated; the target-breakup phenomenon is considerably reduced. In addition, the image contrast and target dynamic range are increased. When the array element position error is negligible and the SNR is high, the improvements in contrast and dynamic range are both equal to 2SNR.

THE CLEAN PROCESS

1. FORM IMAGE AS FOURIER TRANSFORM OF MEASUREMENTS OF RADIATION FIELD.
2. FIND BRIGHTEST SPOT IN IMAGE.
3. MEASURE COMPLEX AMPLITUDE $AE^{j\phi}$ AND POSITION U,V OF BRIGHTEST TARGET.
4. CALCULATE RADIATION FIELD AT ARRAY DUE TO A SOURCE $AE^{j\phi}$ AT LOCATION U,V.
5. SUBTRACT RADIATION FIELD FROM MEASURED DATA.
6. FORM NEW IMAGE.
7. NEW IMAGE IS DEVOID OF BRIGHTEST TARGET AS WELL AS ITS SIDELOBES DUE TO THE RADIATION PATTERN $f(U)$ OF ANTENNA.
8. REPEAT PROCEDURE ON NEXT BRIGHTEST TARGET, AND SO ON. WITH SIDELOBES OF ALL LARGE TARGETS ELIMINATED, THE PROCESS WORKS DOWN TO THE NOISE.
9. DEVELOP LIST OF TARGETS A_M AT LOCATIONS U_M, V_M.
10. FORM MAP BY PLOTTING A "MAIN BEAM" CENTERED AT EACH U_M,V_M WITH AMPLITUDE A_M.

Step 5 means that the new image is devoid of the energy of the largest target. This means that not only will the brightest spot of the original image disappear, but also all the sidelobe responses of that largest target. As a consequence, it is safe to search for the next brightest spot with the assurance that it will not be a sidelobe artifact of the largest target. The process is repeated, and each time a target amplitude A_m and angular coordinates u_m, v_m are noted. The process automatically stops when a threshold test is violated. The final image is formed by plotting the two-dimensional main beam (with no sidelobes) with amplitudes A_m at locations u_m, v_m.

TWO THRESHOLDS

The paper derives a necessary condition which, when satisfied, ensures that all targets with intensities greater than certain thresholds can be many decibels below the sidelobe level of the array, which is the purpose of the technique. The result is a considerable expansion of the target dynamic range that an imaging system can handle and a significant improvement in image contrast.

Two thresholds are developed using highly conservative assumptions. The absolute threshold of target intensity at which detection is ensured is below the sidelobe level of the array by approximately twice the signal to noise power ratio. (Weaker assumptions lead to larger improvements but also to the introduction of false targets. The theory of the minimum "safe" threshold has not been developed.) When the necessary condition is not satisfied (because the number of antenna elements in the array may be insufficient for the number of targets) it is not possible to ensure that all the targets will be detected and correctly located at this low a level. The theory develops a second threshold for this case: called the relative threshold, this threshold ensures that the iterative procedure detects and locates the maximum possible number of targets and it stops the procedure before an image artifact or false target is "discovered" to be a target. Only true targets are reported and displayed.

The theory leading to these thresholds is a new contribution to the class of algorithms known as the CLEAN technique. Computer simulations and experiments with microwave imaging demonstrate the effectiveness of the procedure.