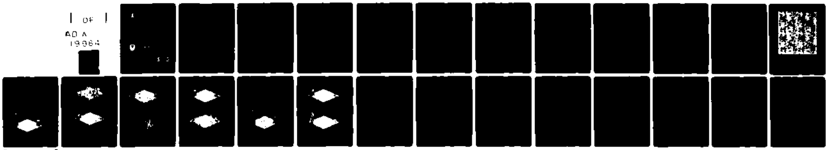
AD-A119 964 ARMY MISSILE COMMAND REDSTONE ARSENAL AL RESEARCH D--ETC F/G 9/1
MEDIAN FILTERING OF SPECKLE NOISE.(U)
FEB 82 N C GALLAGHER, D W SWEENEY
UNCLASSIFIED DRSMI/RR-82-6-TR SBI-AD-E950 297 NL

1 OF 1
AD A
119964



END
DATE
FILMED
11-82
DTIC

TECHNICAL REPORT RR-82-6

# MEDIAN FILTERING OF SPECKLE NOISE

N. C. Gallagher, D. W. Sweeney, and C. R. Christensen
Research Directorate
US Army Missile Laboratory

8 FEBRUARY 1982

**U.S. ARMY MISSILE COMMAND**
*Redstone Arsenal, Alabama 35898*

*Approved for public release; distribution unlimited.*

## DISPOSITION INSTRUCTIONS

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

## DISCLAIMER

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

## TRADE NAMES

USE OF TRADE NAMES OR MANUFACTURERS IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL INDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL HARDWARE OR SOFTWARE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>RR-82-6 | 2. GOVT ACCESSION NO.<br>AD-A114 904 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>MEDIAN FILTERING OF SPECKLE NOISE | | 5. TYPE OF REPORT & PERIOD COVERED<br>Technical Report |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>N. C. Gallagher, D. W. Sweeney, and C. R. Christensen | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Commander, US Army Missile Command<br>ATTN: DRSMI-RR<br>Redstone Arsenal, AL 35898 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Commander, US Army Missile Command<br>ATTN: DRSMI-RPT<br>Redstone Arsenal, AL 35898 | | 12. REPORT DATE<br>8 February 1982 |
| | | 13. NUMBER OF PAGES<br>23 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Imaging
Speckle
Coherent
Digital
Filtering
Median

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A digital model was developed which simulates the physical process of speckle noise generation in coherent imagery. This was used to determine the effectiveness of two-dimensional digital filters for the reduction of speckle noise. Median filters, ranked order filters, and separable combinations of these were evaluated and found to yield good improvement in image signal-to-noise ratios.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

## I. INTRODUCTION

Speckle noise appears when images are formed by use of coherent radiation at any wavelength, including infrared and microwave wavelengths used for imaging through fog and smoke. Investigation has begun into the application of median filters for the removal of speckle noise. Past work in the use of median filters for speckle removal has not been a great success; however, it has been found that the root signal concept may be the key to the productive application of median filters. A root signal for a median filter is a signal that is invariant to the filter; the signal is not changed by the filter application. Consequently, for a root signal, the filter output signal is the same as the input signal. With a few special exceptions root signals are locally monotone; they do not contain impulsive components, nor do they contain rapid oscillations of the form usually found in speckle patterns. When a noisy image is presented it can be filtered to a root signal by the repeated application of the median filter; that is, the filter output is filtered again and again by the same filter until a root signal is obtained. Theory has shown that, again with a few exceptions, the repeated application of a filter results in a root signal. Hopefully, the root signal obtained in this manner is a relatively noise-free version of the noisy input signal. The results to date are very encouraging, and are detailed in Section III.

## II. MEDIAN FILTERING

Median filtering is a nonlinear signal filtering scheme originally proposed by Tukey [1] in 1974. The motivation for Tukey's proposal is in part due to the fact that there are situations where linear filtering is inadequate. For example, if a signal displays sharp discontinuities in addition to being corrupted by high frequency noise, then a linear filter designed to eliminate the noise will also smooth out the signal.

The operation of a one-dimensional median filter will be described, then the two-dimensional modification of the median filter will be discussed. Start with a sampled signal of length L and move a window that spans 2N + 1 signal sample points across this signal. The filter output is set equal to the median value of these 2N + 1 signal samples. This filter output value is associated with the time sample at the center of the window. To account for start-up and end effects at the two endpoints of the L-length signal, N samples each are appended to the beginning and the end of the sequence. The appended samples are constant and equal in value to the first and last samples of the original sequence, respectively. There are other ways in which the values of the appended points can be assigned. As an example, consider the binary valued sequence of Figure 1(a), where L = 10 and N = 1; the median filtered signal is plotted below the input signal. The appended values are marked as X's. Figure 1(b) illustrates the filtering of the same input signal as for Figure 1(a), with N = 2. Figure 1(c) illustrates the filtering of the same input signal, with N = 3. The signal of Figure 1 passes undisturbed through the N = 1 filter; however, it is affected by the N = 2 and N = 3 filters. The signal would be reduced to a constant value by an N = 4 filter. One can immediately make the following observations:

(1) Scaling of the input data scales the median by the same factor; $M[a\ x(N)] = a\ M[x(n)]$.

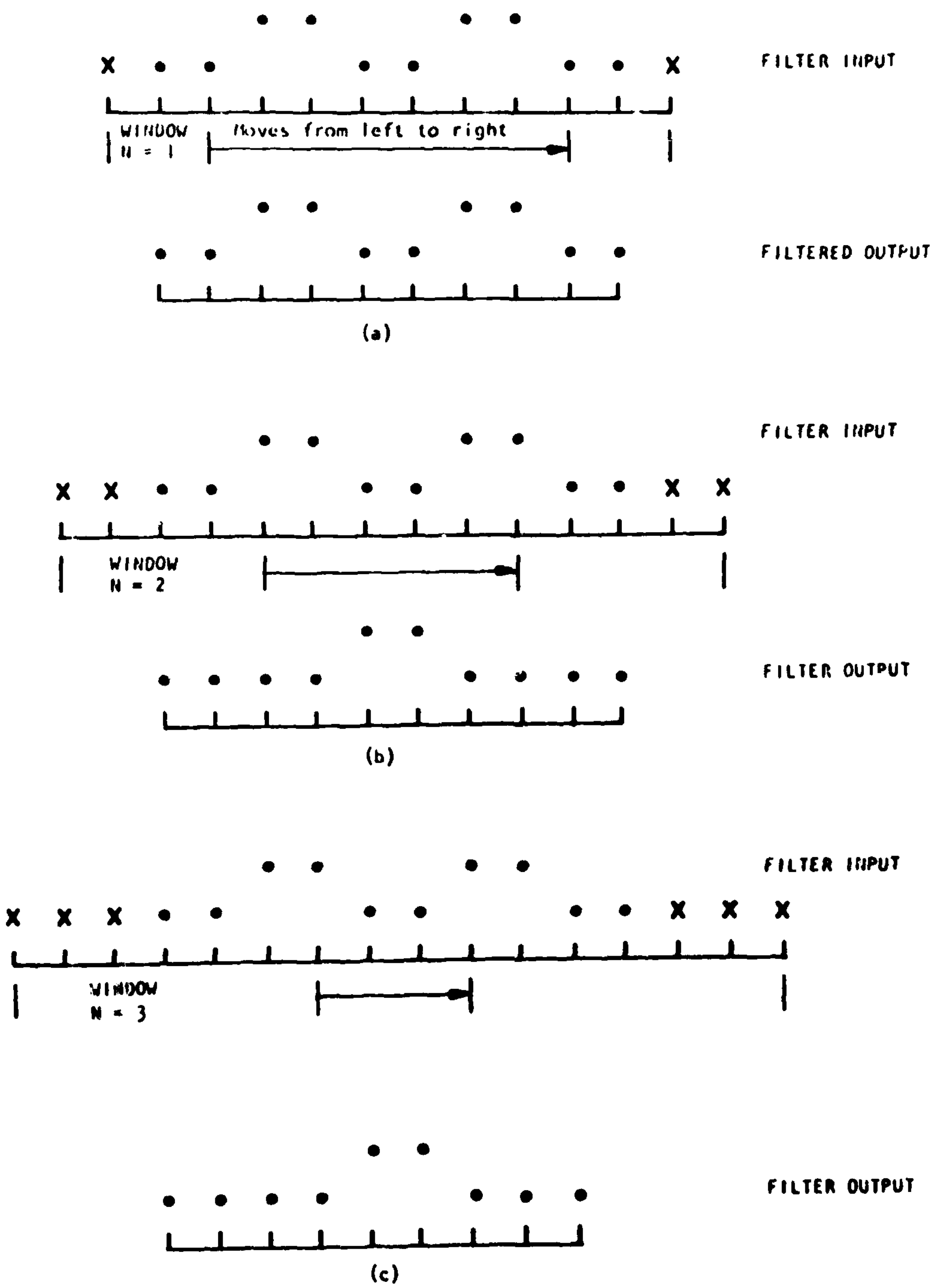



Figure 1. Signal filtered by three different median filters: (a) N = 1, (b) N = 2, and (c) N = 3.

(2) Median filtering preserves edges but removes impulses.

(3) Median smoothers introduce a delay of N.

One observation made by many working with median filters has been that some signal sequences are invariant to the filter process. In addition, it has been observed that any signal, after repeated median filtering, appears to be reduced to one of these invarient signals called a root signal. These phenomena have been proven to be always true [2] and can be stated precisely in the following two theorems:

Theorem 1: Given a length L sequence to be median filtered with a size 2N+1 window, a necessary and sufficient condition for the signal to be invarient under median filtering is that the appended signal consist of constant neighborhoods and edges.

Theorem 2: Upon successive median filter window passes any non-root signal will become a root after a maximum of (L-2)/2 successive filterings. Also, any non-root signal cannot repeat, and the first point to change value on any pass of the filter window will remain constant upon successive passes.

In order to understand the first theorem, a rigorous definition of a constant neighborhood and of an edge are required. These are:

(1) A constant neighborhood is at least N+1 consecutive identically valued points.

(2) An edge is a monotonic sequence connecting two constant neighborhoods with different values.

As a practical example of theorem 2, Figure 2 contains an example of a signal filtered to a root in three passes of a size five window.

A modification of the concept of a median filter is the concept of a recursive median filter. To implement the recursive filter, slide the window across the signal and find the median value as before. Now, after finding the median value, the central sample within the window is assigned this median value before the window is incremented to the next position. The significant property of the recursive filter is that the output is a root after only a single pass. In addition, this root is not the same root after repeated filtering with a conventional median filter. Also, it has not been proven that the set of possible roots for a recursive filter is identical to the set of roots for the conventional non-recursive filter. Figure 3 shows the original signal from Figure 2 filtered to a root by use of a recursive filter.

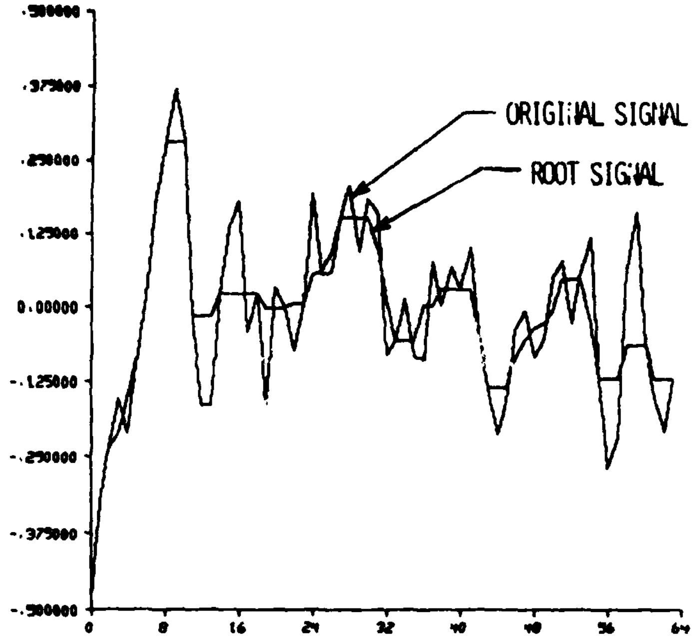



Figure 2. Signal filtered to a root in three passes by a size five window.

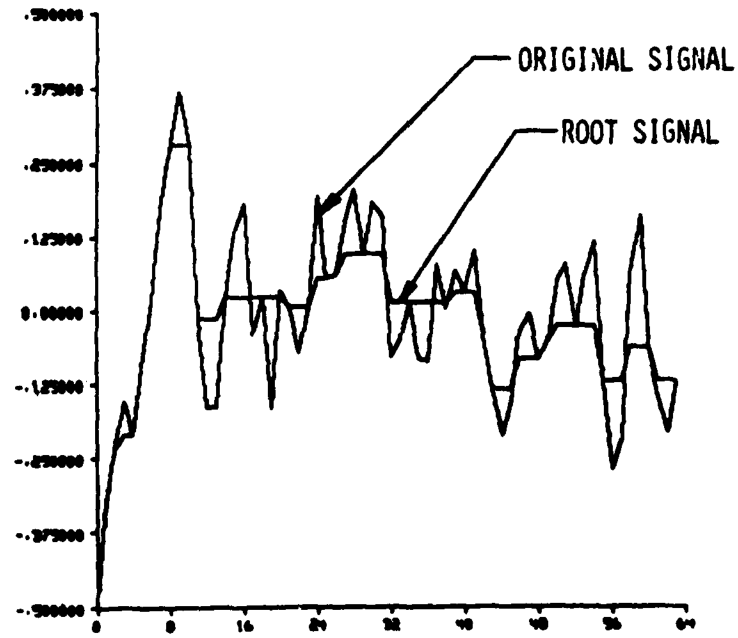



**Figure 3. Signal filtered to a root in one pass by a recursive median filter. Window size is five.**

Among the modifications of median filtering that have been studied are:

(1) Filtering to a sample rank other than the median.

(2) Combining various linear operations with the median filter.

The n'th rank filter is one in which the sample values within the window at any given position are ranked. The filter output is the n'th largest sample value rather than the median value. These non-median n'th rank operations have potential applications in areas such as peak detection with impulse rejection and digital AM detection. As an example of AM detection, consider the example illustrated in Figures 4 and 5 of a 5 KHz tone modulating a 31 KHz carrier sampled at 250 KHz. The envelope is detected by use of a window of size 9 where n = 8 (i.e., the next to largest window sample is chosen as the filter output). Figure 4 shows detection of the noise free signal, and Figure 5 shows detection of the same signal but with impulsive noise added. The way in which this filter detects the signal while simultaneously rejecting the impulsive noise is very impressive.

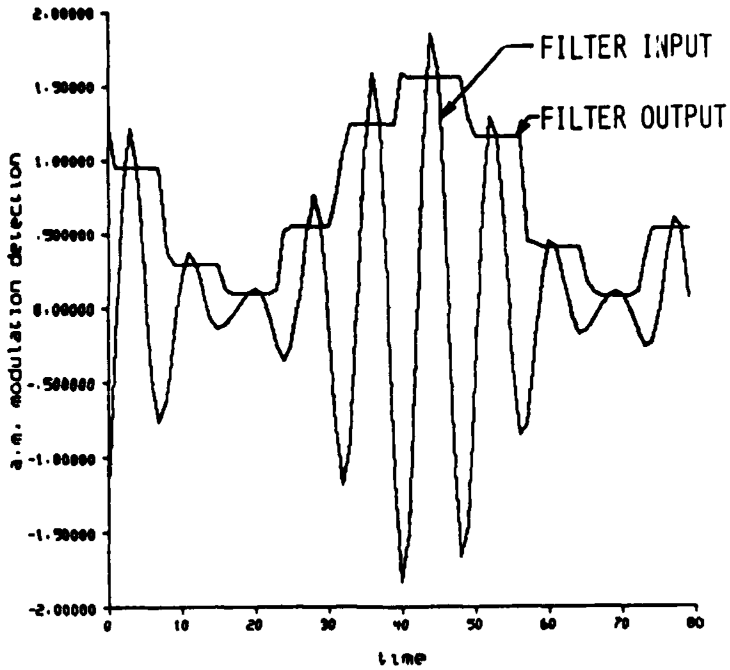



Figure 4. AM signal envelope detected by a n'th rank filter with window size 9 and n = 8.

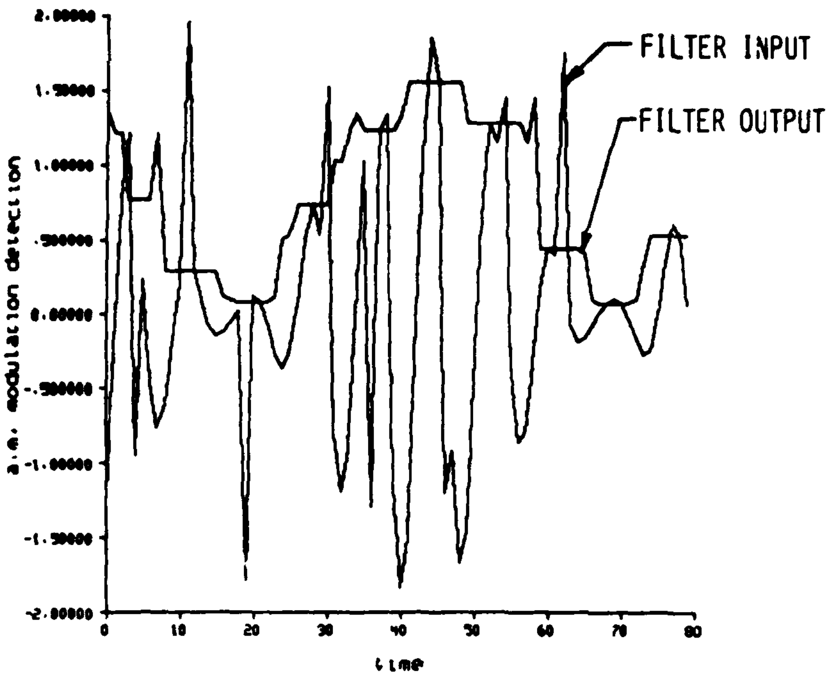



Figure 5. AM signal of Figure 4 with impulse noise added. Signal is enveloped detected by n'th rank filter with window size 9 and n = 8.

## III. FILTERING SPECKLE NOISE

Another important area of application for median filters is the filtering of coherent speckle noise from images. Pure speckle noise can be modeled as a complex valued Gaussian process. Speckle noise is multiplicative; that is, the intensity of the noisy image is the product of the intensity of the noise free image and the intensity of the pure speckle noise process. An easy method by which to simulate the speckle noise process is to use the fast Fourier transform algorithm. The theoretical results found in [2] show that the discrete Fourier transform of a complex valued sequence with deterministic magnitude and random phase will behave as a complex Gaussian process. It is possible to control the correlation function of this process by properly choosing the deterministic magnitude of the sequence to be transformed. If all of these magnitude terms have the same constant value (such as one unit), then the transformed process will be a white noise process. If some of the original magnitude values are changed from their constant value of one and their value set to zero, then the transformed process will have increased correlation among neighboring sample values. In this way it is possible to vary the speckle size. A digitally generated speckle noise intensity field is shown in Figure 6.

In order to generate an image corrupted by speckle noise, the intensity of the image pattern is multiplied by a speckle noise pattern generated as described above. It is then possible to study the effects of different noise removal schemes on this simulated noisy image. In this investigation a two-dimensional median filter is employed to filter the noisy signal to a

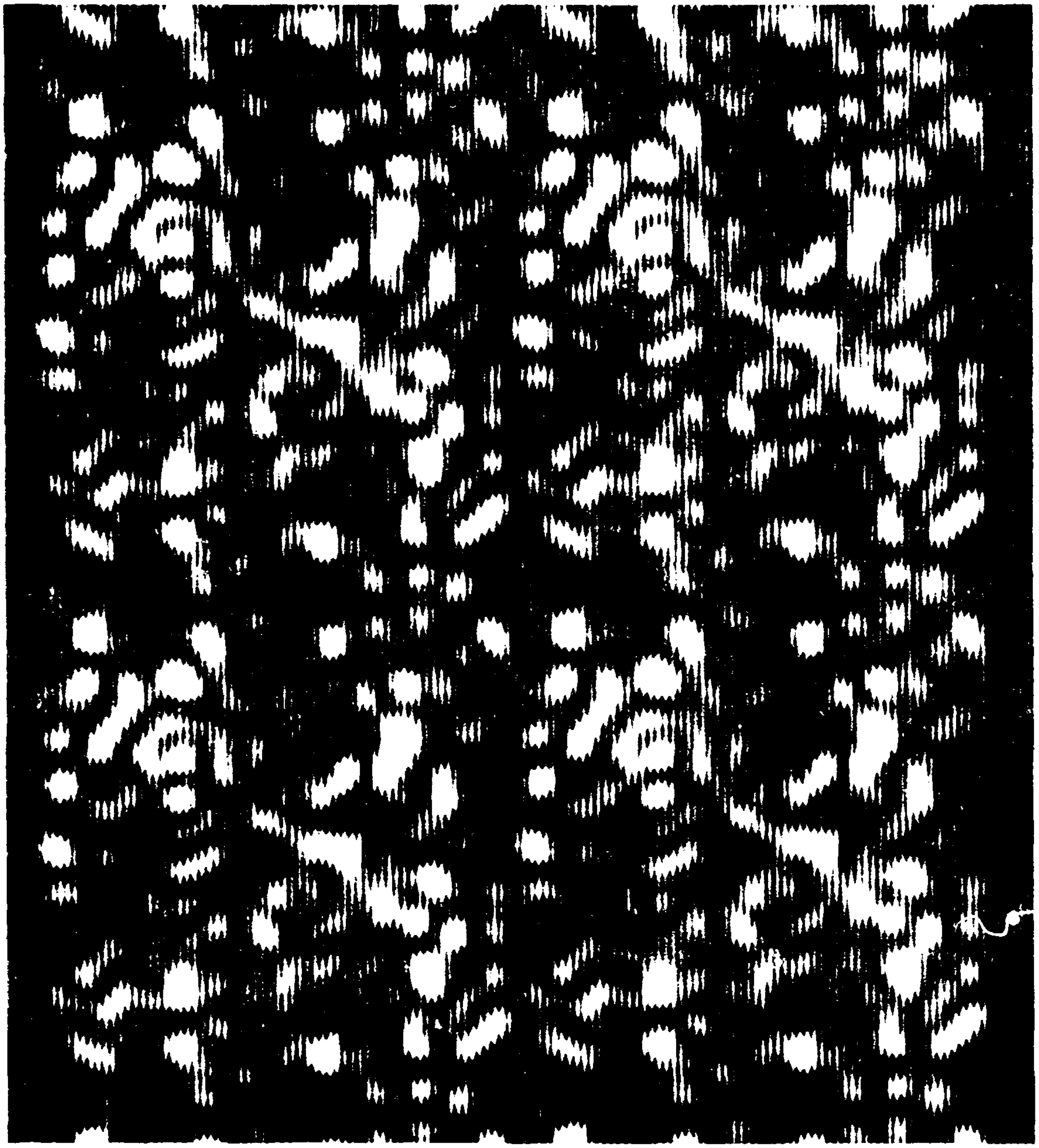


Figure 6. Simulated speckle noise intensity field generated by Fourier transformation of a two-dimensional array with random phase.

root pattern. As in the one-dimensional case, the median filter operates by sliding a window across the signal; then, the median value (or other rank) of all the point values in the window is determined as the filter output. Unlike the one-dimensional case, the window now has shape; however, a square shape is usually chosen for the window.

The key to success for this application of median filtering is to have the original uncorrupted image be itself a root signal. Then when the noisy image is filtered to a root, the result obtained should not be too unlike the original pattern. Of course, the quality of the filtered image will depend on the contrast of the original image. However, at this time a more quantitative discussion cannot be given, nor can the filtered image quality be related to the original signal to noise ratio. Several examples will be presented to illustrate the power and flexibility of the median filter.

For the first example, as shown in Figure 7, three 10 x 10 square targets in a 64 x 64 element field will be used. This image is multiplied by the speckle intensity pattern in Figure 8, in which the average speckle linear dimension, taken as the first zero of the autocorrelation function, is two. The noisy image produced is shown in Figure 9. This noisy image is median filtered repeatedly using a 3 x 3 window until a root is obtained; this root pattern is shown in Figure 10. A second speckle noise intensity pattern with an average speckle linear dimension of four is shown in Figure 11. The noisy image produced by use of this pattern in found in Figure 12. The root pattern produced by median filtering with a 3 x 3 window is illustrated in Figure 13. Note that as the speckle size increases to that of the filter window, the filtered image has more noise.

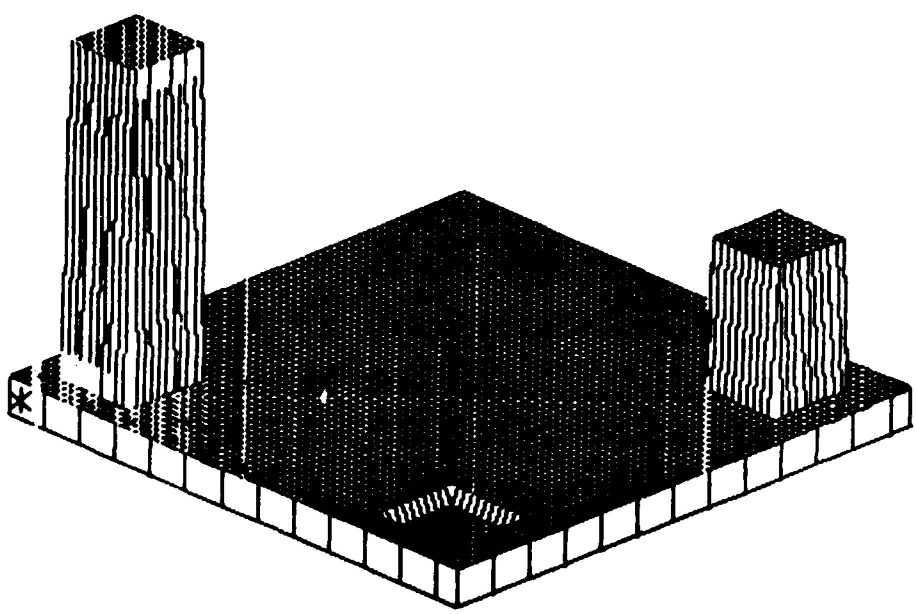


**Figure 7. Original image for speckle noise examples.**

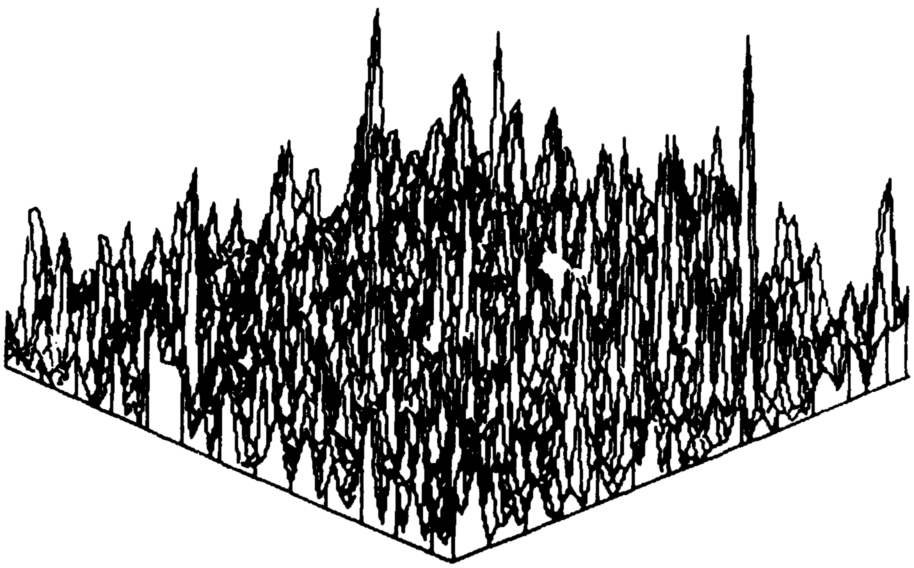


Figure 8. Noise pattern with 2 x 2 speckle size.

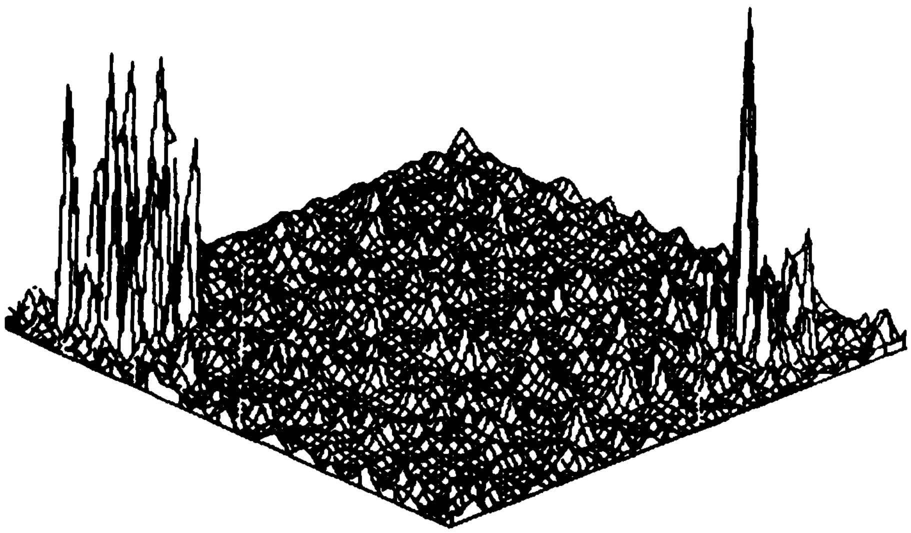


Figure 9. Noisy image made by the multiplication of the original image and speckle pattern in Figure 8.

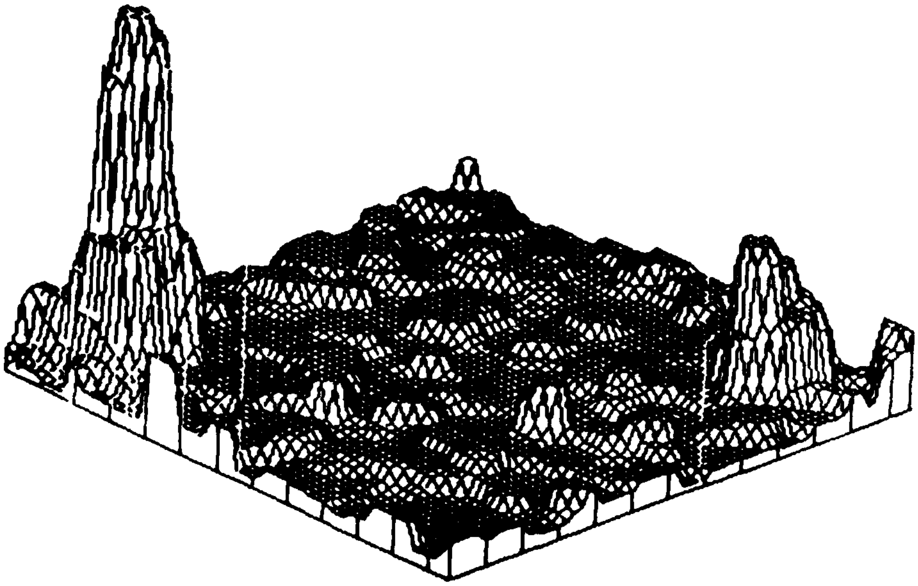


Figure 10. Noisy image filtered to a root by a 3 x 3 square window median filter.

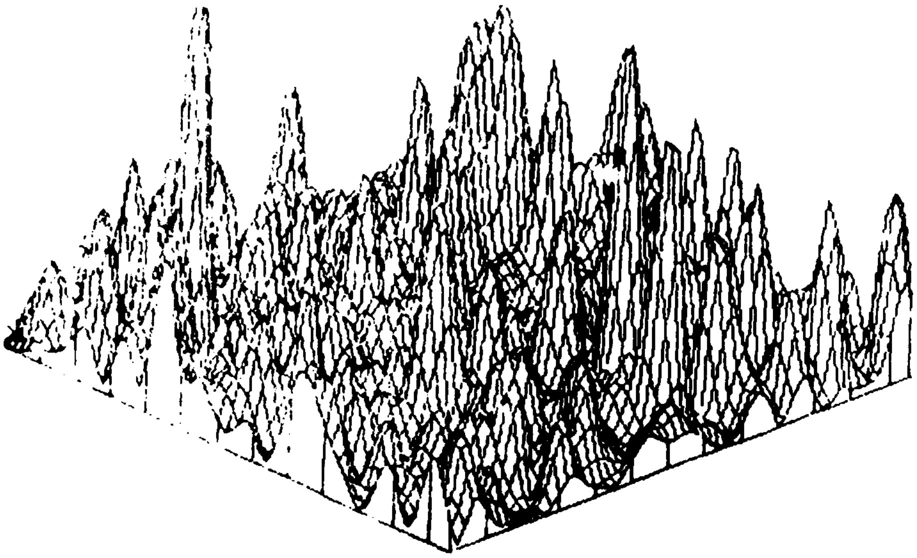


**Figure 11. Second speckle pattern with 4 x 4 speckle size.**

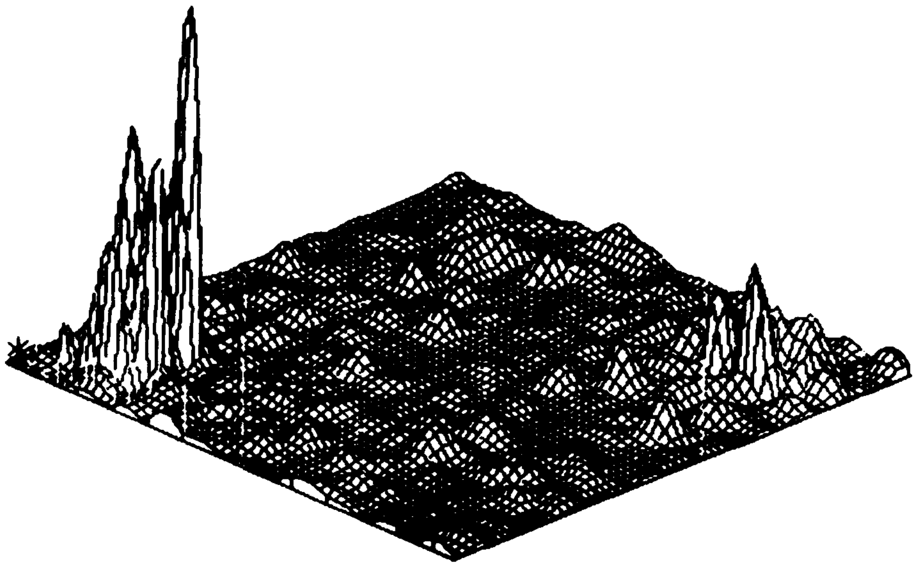


Figure 12. Noisy image pattern corresponding to speckle noise of previous image.

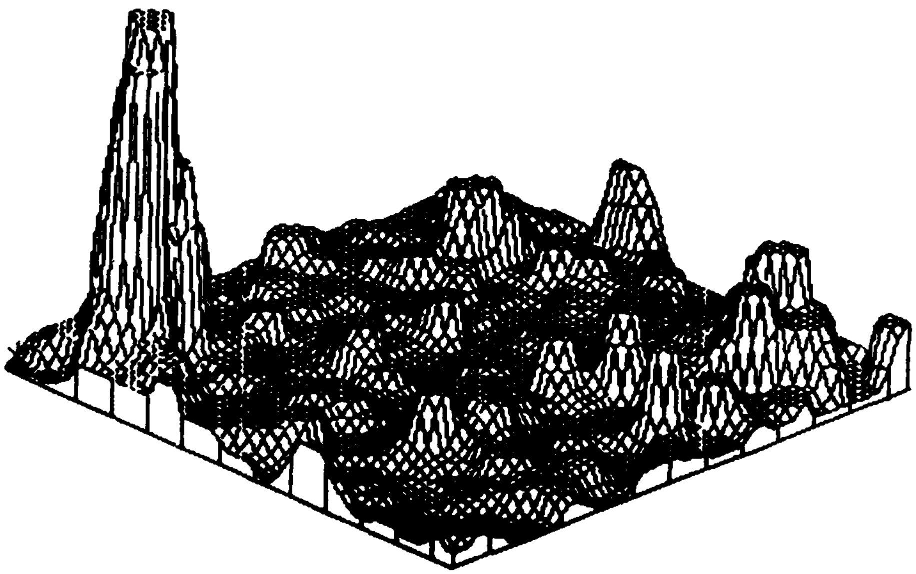


**Figure 13. Noisy image of previous figure filtered to a root.**

Some impressive results have been obtained with modifications of the median filter. One approach that has been particularly fruitful has been to combine different types of median filters. One such filter is called a separable filter. A separable filter is actually the combination of two one-dimensional filters. To use a separable filter, pass a one-dimensional filter window across the entire image pattern. Then pass a second window across the window. For example, the first pass could be 9 samples long and 1 sample long, and the second pass 1 sample long and 9 samples wide; with the result of this combined operation is to make one pass of a 9 x 9 separable filter. The operations of a separable ranked order filter and a separable median filter were combined to obtain the results in the next example. The original image is shown in Figure 14; the spike in the center is a reference height of 10 units. The noisy image, with an average speckle linear dimension of 4, is found in Figure 15. First, one pass of a 9 x 1 separable ranked filter was made where the output value is the fourth from the largest sample value in the window. Then 3 passes of a 9 x 1 seperable median filter were made. The filtered image is shown in Figure 16. The result is very good.

Although these results have been very encouraging, no firm grasp on how to choose the appropriate type or combination of median filters for a particular application has been obtained. At present, the choices are based on a well-developed intuition rather than a sound theoretical foundation, although this foundation is being developed.

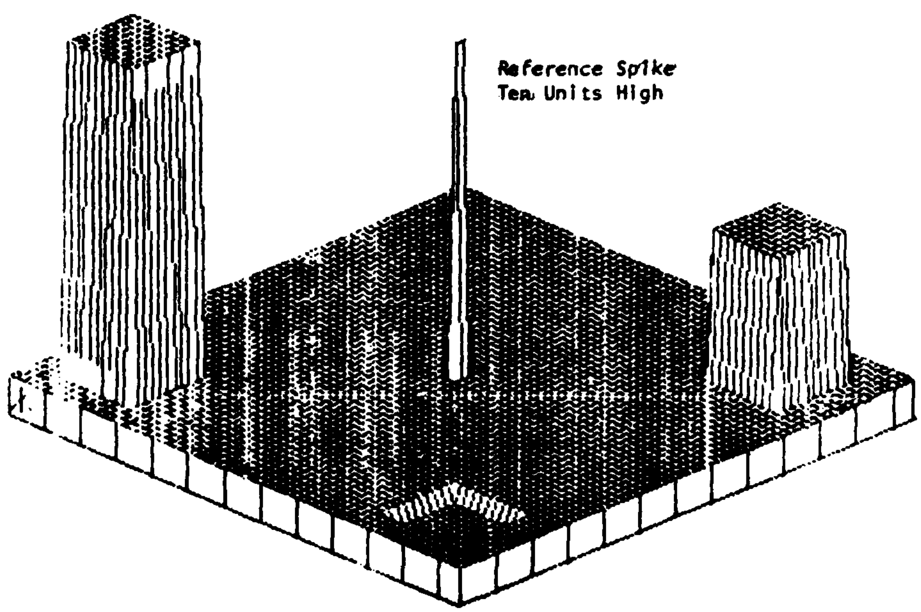



**Figure 14. Original image to be filtered by use of separable ranked order filter and then separable median filter.**

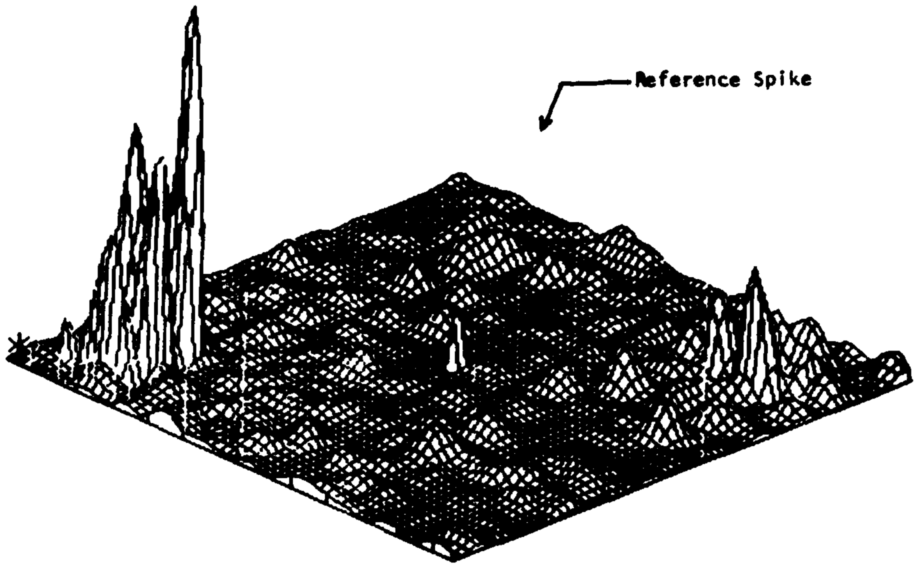



Figure 15. Noisy image corresponding to original of Figure 14 in 4 x 4 speckle.

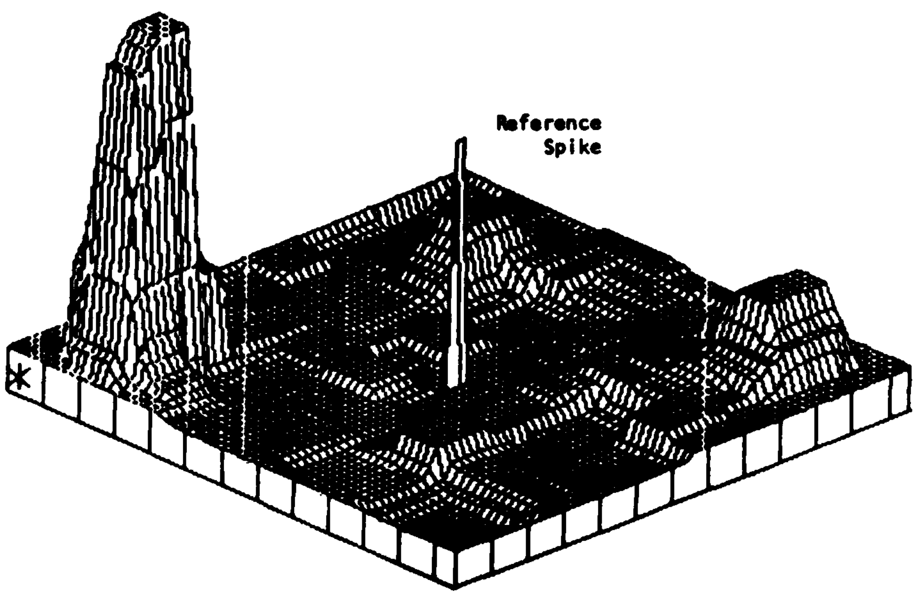



Figure 16. Filtered image corresponding to noisy image of Figure 15.

## IV. DIRECTIONS FOR FUTURE WORK

Median filtering is a relatively new area of digital signal processing; the theoretical basis of median filtering is only now being developed. Much more work is needed to develop analytical design procedures with a sound theoretical foundation rather than the largely intuitive procedures currently employed.

In order to study the effects of median filtering on speckle noise in coherently generated images, a true model for the simulation of speckle noise is required. The procedure discussed in this report for the generation of simulated speckle by using the FFT of a random phase sequence appears to provide the required flexibility. Efficient computer algorithms for the simulation of optical propagation in the Fresnel zone are now required. Such algorithms should make use of efficient sampling procedures such as the hexagonal sampling raster as well as efficient discrete transform methods for these sampling schemes. The existence of such fast and efficient algorithms combined with FFT speckle simulation should provide powerful digital techniques for the simulation of coherent optical propagation. This would, therefore, allow meaningful theoretical studies as well as computer simulations for the median filtering of speckle noise.

One specific question that needs to be addressed is the relationship between speckle size and shape, median window size and shape, and image resolution in the filtered signal. Also, additional work is needed on the properties of two-dimensional root signals in median filters, which in some respects seem to be quite different from the one-dimensional root properties. At present, the theory for two-dimensional median filters remains undeveloped.

## REFERENCES

1. J. W. Tukey, "Nonlinear (Nonsuperposable) Methods for Smoothing Data," in Cong. Rec., 1974, EASCON, p. 673.

2. N. C. Gallagher and G. L. Wise, "A Theoretical Analysis of the Properties of Median Filters," to appear in IEEE Transactions on Acoustics, Speech and Signal Processing.

# DISTRIBUTION

| | No. of Copies |
|---|---|
| Commander, US Army Research Office | |
| ATTN: DRXRO-PH, Dr. R. Lontz | 5 |
| Dr. B. D. Guenther | 1 |
| P. O. Box 12211 | |
| Research Triangle Park, NC 27709 | |
| | |
| US Army Research and Standardization Group (Europe) | |
| ATTN: DRXSN-E-RX/LTC D. R. Reinhard | 1 |
| Box 65 | |
| FPO New York 09510 | |
| | |
| Commander, US Army Materiel Development and Readiness Command | |
| ATTN: Dr. James Bender | 1 |
| Dr. Gordon Bushey | 1 |
| 5001 Eisenhower Avenue | |
| Alexandria, VA 22333 | |
| | |
| Headquarters, Department of the Army | |
| Office of the DCS for Research, Development and Acquisition | |
| ATTN: DAMA-ARZ | 1 |
| Room 3A474, The Pentagon | |
| Washington, DC 20301 | |
| | |
| OUSDR&E | |
| Room 3D1079, The Pentagon | 1 |
| Washington, DC 20301 | |
| | |
| Director | |
| Defense Advanced Research Projects Agency | |
| 1400 Wilson Boulevard | 1 |
| Arlington, VA 22209 | |
| | |
| OUSDR&E | |
| ATTN: Dr. G. Gamota | |
| Deputy Assistant for Research (in Advanced Technology) | |
| Room 3D1067, The Pentagon | 1 |
| Washington, DC 20301 | |
| | |
| Director, Defense Advanced Research Projects Agency/STO | |
| ATTN: Commander T. F. Wiener | 1 |
| D. W. Walsh | 1 |
| 1400 Wilson Boulevard | |
| Arlington, VA 22209 | |
| | |
| Commander, US Army Aviation Systems Command | |
| 12th and Spruce Streets | |
| St. Louis, MO 63166 | 1 |
| | |
| Director, US Army Air Mobility Research and Development Laboratory | |
| Ames Research Center | 1 |
| Moffett Field, CA 94035 | |

Commander, US Army Electronics Research and Development Command
ATTN: DRSEL-TL-T, Dr. Jacobs 1
DELEW-E, Henry E. Sonntag 1
Fort Monmouth, NJ 07703

Director, US Army Night Vision Laboratory
ATTN: John Johnson 1
John Deline 1
Peter VanAtta 1
Fort Belvoir, VA 22060

Commander
US Army Picatinny Arsenal 1
Dover, NJ 07801

Commander
US Army Harry Diamond Laboratories
2800 Powder Mill Road
Adelphi, MD 20783 1

Commander, US Army Foreign Science and Technology Center
ATTN: W. S. Alcott 1
Federal Office Building
220 7th Street, NE
Charlottesville, VA 22901

Commander
US Army Training and Doctrine Command 1
Fort Monroe, VA 22351

Director, Ballistic Missile Defense Advanced Technology Center
ATTN: ATC-D 1
ATC-O 1
ATC-R 1
ATC-T 1
P. O. Box 1500
Huntsville, AL 35808

Commander, US Naval Air Systems Command
Missile Guidance and Control Branch 1
Washington, DC 20360

Chief of Naval Research
Department of the Navy
Washington, DC 20301 1

Commander
US Naval Air Development Center 1
Warminster, PA 18974

Commander, US Naval Ocean Systems Center
Code 6003 1
Dr. Harper Whitehouse
San Diego, CA 92152

Director, Naval Research Laboratory
ATTN: Dave Ringwolt 1
Code 5570, T. Gialborinzi 1
Washington, DC 20390

Commander, Rome Air Development Center
US Air Force
ATTN: James Wasielewski, IRRC 1
Griffiss Air Force Base, NY 13440

Commander, US Air Force, AFOSR/NE
ATTN: Dr. J. A. Neff 1
Building 410
Bolling Air Force Base
Washington, DC 20332

Commander
US Air Force Avionics Laboratory
ATTN: D. Rees 1
W. Schoonover 1
Dr. E. Champaign 1
Dr. J. Ryles 1
Gale Urban 1
David L. Flannery 1
Wright Patterson Air Force Base, OH 45433

Commander, AFATL/LMT
ATTN: Charles Warren 1
Eglin Air Force Base, FL 32544

Environmental Research Institute of Michigan
Radar and Optics Division
ATTN: Dr. A. Kozma 1
Dr. C. C. Aleksoff 1
Juris Upatnieks 1
P. O. Box 618
Ann Arbor, MI 41807

IIT Research Institute
ATTN: GACIAC
10 West 35th Street 1
Chicago, IL 60616

Dr. J. G. Castle
9801 San Gabriel, NE 1
Albuquerque, NM 87111

Dr. Vincent J. Corcoran
2034 Freedom Lane
Falls Church, VA 22043 1

Optical Science Consultants
ATTN: Dr. D. L. Fried 1
P. O. Box 388
Yorba Linda, CA 92686

Commander, Center for Naval Analyses
ATTN: Document Control 1
1401 Wilson Boulevard
Arlington, VA 22209

Raytheon Company
ATTN: A. V. Jelalian 1
528 Boston Post Road
Sudbury, MA 01776

Dr. J. W. Goodman
Information Systems Laboratory
Department of Electrical Engineering 1
Stanford University
Stanford, CA 94305

Eric G. Johnson, Jr.
National Bureau of Standards
325 S. Broadway
Boulder, CO 80302 1

M. Vanderlind
Battelle Columbus Labs 1
505 Ring Ave
Columbus, OH 43201

Dr. Nicholas George
The Institute of Optics 2
University of Rochester
Rochester, NY 14627

Naval Avionics Facility 1
Indianapolis, IN 46218

F. B. Rotz
Harris Corporation
P. O. Box 37 1
Melbourne, FL 32901

Robert L. Kurtz
TAI Corporation 1
8302 Whitesburg Dr., SE
Huntsville, AL 35802

J. R. Vyce
Itek Corporation 1
10 Maguire Road
Lexington, MA 02173

Dr. David Cassasent 1
Carnegie Mellon University
Hamerschage Hall, Room 106
Pittsburg, PA 15213

K. G. Leib
Research Department 1
Grumman Aerospace Corporation
Bethpage, NY 11714

Terry Turpin
Department of Defense
9800 Savage Road 1
Fort George G. Meade, MD 20755

Dr. Stuart A. Collins
Electrical Engineering Department 1
Ohio State University
1320 Kennear Road
Columbus, OH 43212

Mike Scarborough, MS-19
Teledyne Brown Engineering 1
Cummings Research Park
Huntsville, AL 35807

Commander
AFEL 1
Hanscom Air Force Base, MD 01731

Dr. Arthur N. Chester 1
Dr. Donald H. Close 1
Thomas R. O'Meara 1
Dr. Wilfried O. Eckhardt 1
Hughes Research Laboratories
3011 Malibu Canyon Road
Malibu, CA 90265

TRW
Defense and Space Systems Group
One Space Park 1
ATTN: Dr. Peter O. Clark
Redondo Beach, CA 90278

H. J. Caulfield
Aerodyne Research, Inc. 1
Bedford Research Park
Crosby Drive
Bedford, MA 01730

US Army Materiel Systems Analysis Activity
ATTN: DRXSY-MP 1
Aberdeen Proving Ground, MD 21005

US Army Night Vision Laboratory 1
ATTN: DELNV-L, Dr. R. Buser
Fort Belvoir, VA 22060

| | |
|---|---|
| DRCPM-PE-E, John Pettitt | 1 |
| -PE | 1 |
| | |
| DRSMI-LP, Mr. Voigt | 1 |
| -O | 1 |
| -Y | 1 |
| -RN, Jerry Hagood | 1 |
| -RE, W. Pittman | 1 |
| -RD | 3 |
| -RG | 1 |
| -RG, J. A. McLean | 1 |
| -RR, Dr. R. L. Hartman | 1 |
| Dr. J. S. Bennett | 1 |
| Dr. C. R. Christensen | 100 |
| Dr. J. G. Duthie | 1 |
| -RPR | 15 |
| -RPT, Record Copy | 1 |
| -R | 1 |



☆ U.S. GOVERNMENT PRINTING OFFICE: 1982—546-116/762

END

DATE
FILMED

11-82

DTIC