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DSP APPLICATIONS IN RADAR

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Abstract

There has been an explosive growth in Digital Signal Processing theory and applications over the years. This seminar report explores the applications of digital signal processing in Radar. A survey on applications in Digital Signal Processing in Radar from a wide variety of areas is carried out. A review is done on basic approaching models and techniques of signal processing for different parameters and extracting information from the received signal. The various techniques adopted at different stages of radar to obtain the target's signature, is also briefed.

Introduction

Flexibility and versatility of digital techniques grew in the front-end signal processing and with the advent of integrated digital circuitry, high speed signal processors were developed and realized. Radar continued to grow in the recent years by keeping the future developments in mind and with better digital capability. Significant contributions in DSP in Radar have been in MTI processing, Automatic Detection and extraction of signal, Image reconstruction, etc. A case study on Radar Synthetic Vision System for Adverse Weather Aircraft landing is discussed. In this report an effort is made to identify the contribution of DSP in the advancement of Radars.

I. Modern RADAR

RADAR transmits radio signals at distant objects and analyzes the reflections. Data gathered can include the position and movement of the object, also radar can identify the object through its "signature" - the distinct reflection it generates. There are many forms of RADAR - such as continuous, CW, Doppler, ground penetrating or synthetic aperture; and they' re used in many applications, from air traffic control to weather prediction.
In the modern Radar systems digital signal processing (DSP) is used extensively. At the transmitter end, it generates and shapes the transmission pulses, controls the antenna beam pattern while at the receiver, DSP performs many complex tasks, including STAP (space time adaptive processing) - the removal of clutter, and beamforming (electronic guidance of direction).

The front end of the receiver for RADAR is still often analog due the high frequencies involved. With fast ADC convertors- often multiple channel, complex IF signals are digitized. However, digital technology is coming closer to the antenna. We may also require fast digital interfaces to detect antenna position, or control other hardware.

The main task of a radar' s signal processor isto make decisions. After a signal has been transmitted, the receiver starts receiving return signals, with those originating from near objects arriving first because time of arrival translates into target range. The signal processor places a raster of range bins over the whole period of time, and now it has to make a decision for each of the range bins as to whether it contains an object or not.

This decision-making is severely hampered by noise. Atmospheric noise enters into the system through the antenna, and all the electronics in the radar' s signal path produces noise too.

A. Major blocks of modern radar system

The major components of modern radar are the antenna, the tracking computer and the signal generator. The tracking computer in the modern radar does all the functions. By scheduling the appropriate antenna positions and transmitted signals as a function of time, keeps track of targets and running the display system.

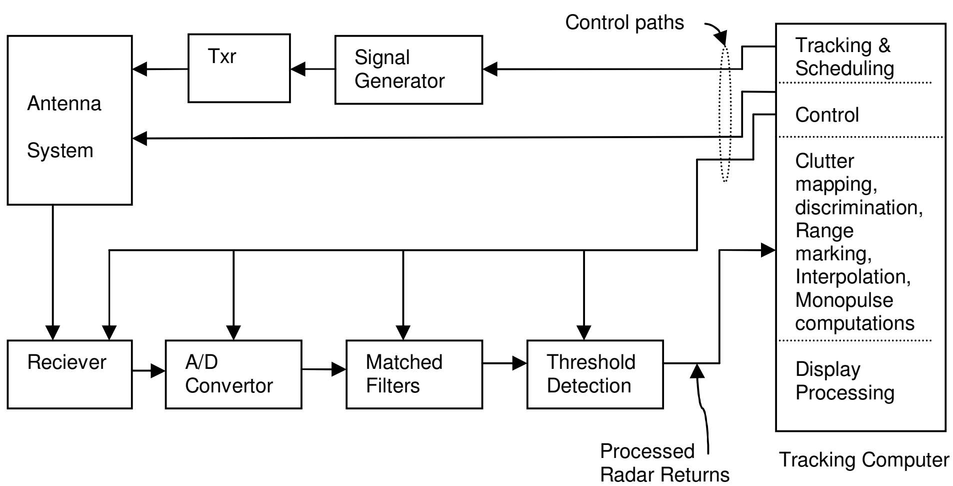


Fig 1. Block Diagram of a Modern Radar system “adopted from [6]”

Even if atmospheric attenuation can be neglected, the return from a distant object is incredibly weak. Target returns often are no stronger than twice the average noise level, sometimes even buried under it. It is quite difficult to define a threshold for the decision whether a given peak is noise or a real target. If the threshold is too high then existing targets are suppressed, that is, the probability of detection (P_D) will drop. If the threshold is too low then noise peaks will be reported as targets, that is, the probability of false alarms (P_{FA}) will rise. A common compromise is to have some 90% probability of detection and a false alarm rate of 10^{-6}.

It maintains a given P_{FA} known as CFAR, for Constant False Alarm Rate. Rather than keeping the threshold at a fixed point, CFAR circuitry inspects one range bin after the other and compares the signal level found there with the signal levels found in its neighboring bins. If the noise level is rather high in all of these (eg, because of precipitation) then the CFAR circuit will raise the threshold accordingly.

Further tasks of the signal processor are:

- **Combining information:** Secondary surveillance radars like those located on airports can ask an aircraft's transponder for information like height, flight number or fuel state. Pilots may also issue a distress signal via the transponder. The ground radar's signal processor combines this data with its own measurements of range and angular direction and plots them all together on the appropriate spot on the scope.
- **Forming tracks:** By correlating the data sets which were obtained in successive scan cycles, the radar can calculate a flight vector which indicates an aircraft's speed and expected position for the next scan period. Airport radars are capable of tracking hundreds of targets simultaneously, and flight safety depends heavily on their reliability. Military tracking radars use this information for gun laying or guiding missiles into some calculated collision point.
- **Resolving ambiguities in range or Doppler measurements**: Depending on the radar's pulse repetition frequency (PRF), the readings for range, Doppler or even both are ambiguous. The signal processor is aware of this and selects a different PRF when the object in question is measured again. With a suitable set of PRFs, ambiguities can be eliminated and the true target position can be determined.
- **Ground Clutter Mapping**: Clutter is the collective term for all unwanted blips on a radar screen. Ground clutter originates from buildings, cars, mountains etc, and a clutter map serves to raise the decision threshold in areas where known clutter sources are located.
- **Time and power management**: Within a window of some 60°x40°, phased array radars can instantly switch their beam position to any position in azimuth and elevation. When the radar is tasked with surveying its sector and tracking dozens of targets, there's a danger of either neglecting part of the search sector or losing a target if the corresponding track record isn't updated in time. Time management serves to maintain a priority queue of all the tasks and to produce a schedule for the beam steering device. Power management is necessary if the transmitter circuitry runs the danger of overheating. If there's no backup hardware then the only way of continuing regular operation is to use less power when less power is required, say, for track confirmation.
- **Countering interference**: Interference can be a) natural, or b) man-made. Natural interference can be heavy rain or hail storms, but also varied propagation conditions. Man-made interference, if created on purpose, is also called jamming and is one of the means of electronic countermeasures.

B. Detection of Signals

Detection is the process by which the presence of the target is sensed in the presence of competing indications which arise from background echoes (clutter), atmospheric noise, or noise generated in the radar receiver. The noise power present at the output of the radar receiver can be minimized by using filter, whose frequency response function maximizes the output peak-signal to mean-noise (power) ratio is called matched filter. we shall discuss the application of digital filtering to matched filters.

C. Fast Convolution Filter implementation[5]

a. Dual pipeline FFT matched Filter

In this system, FFTs are pipelined and both the forward and reverse radix-r FFTs are implemented in hardware. Initial recording of the data is done using input buffer (IB) memory and it takes 'N/r' clock pulses to read N data points and 'r' input rails. The amount of time 'N/r' is called as one epoch. It requires three epochs for the first data to be completely

filtered, and is delivered by one epoch thereafter. In the dual FFT systems arbitrary data is filtered sequentially with arbitrary reference functions selected from reference memory.
Drawback
In many applications the same data set be filtered with several different filters, in this case only one forward transform is performed followed by several inverse transforms, it is possible to eliminate one of the pipeline FFTs. This is desirable since it would save a large amount of hardware.

b. Single forward FFT matched Filter
The data is first transformed and the result stored in the temporary storage memory [TSM]. The data is then multiplied by the filter function and inverse transformed. This allows multiple readouts of the forward transformed data from the TSM and multiple filtering of the same data set; the output of each filter will appear sequentially.
Drawback
The data at the output of the forward FFT are in digit reverse order, it is then corrected by reading the data out of the TSM in digit reversed order. The second FFT is performed the output is placed into an output buffer, and to be read in a bit reversed order from the output buffer.
It requires five epochs for the first data to be completely filtered, and is delivered by one epoch thereafter.

c. Single inverse FFT matched Filter
A single inverse FFT is employed and the data is read from the input buffer in digit reverse order. The data is transformed and stored in TSM in normal order, and then read out in bit reverse order.
Drawback
Complex conjugation must be performed after each transform and stored. The digit reversed access to the IB is required and the IB may quite large compared to TSM and may be difficult to implement.

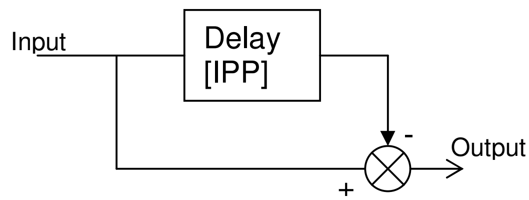
d. Reconfigurable FFT Matched Filter
The FFT subsystem switches the interstage delay lines to realize both forward and reverse transforms.
Forward Transform: By routing the data through the interstage delay memories [IDMs] in decreasing order
Inverse Transform: by sending data through the IDMs in the increased order of size.
The total memory of each stage is the number of delay lines memories.

Comparison of 4 matched Filter systems
The relative performance of Dual Pipeline matched Filter is fastest but requires two complete pipeline FFTs hence more hardware is required.
Single inverse transform matched Filter has better performance over Single forward transform matched Filter and also doesn't require a double buffered output memory.
Reconfigurable FFT matched filter is preferred and chosen most of the times, it doesn't require digit reversed to the IB and also doesn't require digital recording of TSM.

II. Doppler processing[5]
Doppler processing is used to filter out clutter and thereby reveal fast moving targets. Such filters are implemented digitally, FFT or a set of transversal filters. Cancellers and few optimized methods are some of the Clutter rejection techniques:

A. Cancellers

Clutter rejection filter amounts to the design of FIR digital filter with stopbands to reject the clutter frequency component. A simple filter is a two-pulse cancellor.



A two-pulse canceller is used if the clutter component [assuming DC only] remains constant in a given range bin and can be eliminated by subtracting the output from two successive pulses. The transfer function of two-pulse canceller is equal to $1-z^{-1}$. And is equivalent to FIR digital filter with magnitude response $\sin(\omega/2)$.

In practice, the clutter have a power spectrum that covers frequencies above DC. The two-pulse canceller will attenuate low frequency components but may not totally reject clutter. A three-pulse canceller with its transform function equivalent to FIR filter is $0.5+z^{-1}+0.5z^{-2}$. This attenuates further the components near DC.

Other Optimum Design Methods

These are based on the assumption of the clutter and the desired signal.

a. Delong Hofstetter Technique

Under the constraint of the known clutter spectrum, in this technique the Signal-to-interference ratio is maximized at a given Doppler frequency, if the clutter were white Gaussian Noise, the matched filter would be optimum signal processor.

b. Another approach

Clutter is located in frequency bands disjoint from the band occupied by the signals of moving targets. If the clutter is near DC, then a with an high pass filter the clutter frequencies are within the stop band, and pass band passes the desired signals. These signals are then passed through narrowband pass filters.

B.Implementation of Clutter Filter

The returns from the same range bin over several pulses are linearly combined to form the output per IPP, each delay of Δ can be realized using shift register.

a. The direct implementation of the optimum linear processor with N points requires N multiplications per output point. Since a different optimum processor is designed for each Doppler channel, the filter tap weights are different for each channel.

b. A simpler Suboptimum Processor is obtained by cascading a three-pulse cancelor with a bank of bandpass filters(implemented by a sliding FFT). N-point FFT requires $N\log_2 N$ multiplications; only $\log_2 N$ multiplications are required per each Doppler Channel. Thus significant hardware simplifications are possible with this scheme provided its performance is adequate.

Eg:- moving Target Detector

MTI Signal Processing

A major task in moving target indicator (MTI) radar is to obtain a time-domain filter, with the introduction of digital technology, these are achieved using digital transversal filters, recursive filters and filter banks.

III. Adaptive Thresholding and Automatic Detection[8]

Digital processing permitted the reference level to be generated/internally from the observations themselves, thereby permitting more sensitive and faster thresholds. Most of the Radars employ automatic detection circuits to maintain, ideally, a constant false alarm rate [CFAR] by generating estimates of the receiver output. Automatic target detection for a search radar can be achieved by comparing the processed voltage in each cell to

1. A fixed threshold level.
2. Threshold levels based upon the mean amplitude of the ambient interference.
3. A level computed on the basis of partial [a prior] knowledge of the interference distribution.
4. A threshold level determined by distribution-free statistical hypothesis testing that assumes no a priori knowledge of the statistical distribution of the interference.

In first case a detection decision is made if the processed signal r_o , is equal or greater than a present threshold. That is, if $r_o \geq T_p$, a detection is declared.

The second and third cases represent adaptive threshold CFAR processors. In these processors, estimates of the unknown parameters of the known distribution of the processed interference are formed. In the second case can achieve CFAR when the distribution of the processed interference is completely described by its mean level. The third case forms estimates of the unknown parameters of the known [a priori] distribution.

The fourth case are called nonparametric CFAR processors. These distribution-free process form a test variable whose statistics are independent of the distribution of the input [nonprocessed] interference.

A. Adaptive Threshold CFAR processors

The Adaptive threshold CFAR processors is applicable to situations were the distribution of the processed data [in the no-signal case] is known generally and unknown parameters associated with the distribution can be estimated. It is often implemented as moving or sliding window through which estimates of the unknown parameters of the interference are formed.

B. Distribution free CFAR processors

These provide CFAR characteristics when the background return has a unknown distribution. These processors remain insensitive to variations in the distribution, and generally experiences additional detection loss their CFAR properties make their application advantageous.

1. Double Threshold Detector
2. Modified double threshold Detector
3. Rank order Detector
4. Rank-sum double quantizer Detector

C. SCANNING Radar Applications[8]

The optimum processor for a pulsed, noncoherent waveform on *n* pulses is a square law detector followed by a *n* pulse noncoherent integrator that uses equal weighting of each detected pulse.

The integrator must not only be realizable in practical sense but also

1. provide a small detection loss as possible
2. provide a means of minimizing losses associated with integration sample window and scanning beam straddle of the target
3. In track-while scan applications, permit accurate measurements of the target angular position.

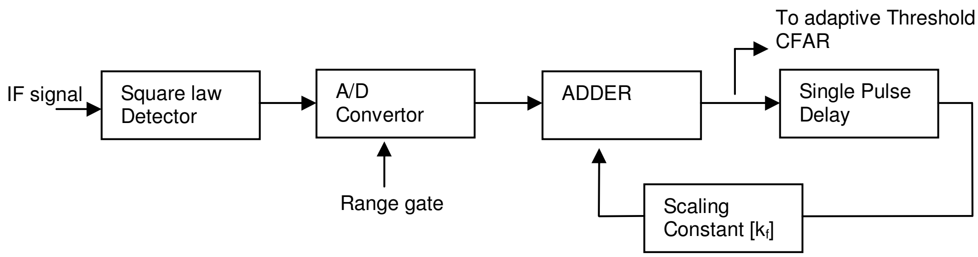


Fig. Square law detector “from [8]”

Integrators that are typically configured are sliding window. And this requires the storage of data for n interpulse periods.
The single–loop processor requires storage of data for the single interpulse period. Of course, if data memory is somehow restricted and if performance is acceptable the feedback approach is preferred and single feedback loop is shown below.

IV. Case Study - Radar Synthetic Vision System[1]

One of the solutions during the adverse weather landing is to use a radar imaging system. In this section we will discuss the prototype section for aiding pilots to land in zero visibility weather conditions. In this section we will describe a synthetic vision system (SVS). This system provides a runway image to the allow pilots to see through fog and adverse weather. The SVS system[9] consists of an electro mechanically scanned antenna, transmitter, millimeter wave integrated circuit (MMIC) receiver, display processor and heads up display (HUD).
Images are enhanced using beam sharpening, noise reduction, and motion compensation processing techniques prior to the critical transformation from radar coordinates to true pilot perspective for display on the HUD. In this system Versa module Eurocard (VME) platform is used. Single antenna operation by using a circular and isolating Positive-Intrinsic-Negative (PIN) diode switch in duplexer. The receiver system consists of a low noise GaAs Field-effect Transistor (FET) MMIC receiver. The received and amplified signal is down converted twice. The detected output is sent to display processor for digitization, signal processing and to the display unit.
SVS Display Processor and Raw Data Recording
The raw digitizer radar video data recording obtains snapshots at 4s intervals with a total recording time of 600s. During aircraft approach the control processor is interrupted by the IRIG Time Code Slave every 4s, which signals, to the control processor that a raw digitizer frame acquisition are to be performed. The control processor stores the next immediate frame after antenna retraces.

A. Image Enhancement

Imagery that are obtained by scanning millimeter (MMW) radars suffer from multitude of quality degradations. The solutions for the degradation such as poor contrast, angular loss and motion induced distortion are considered. The source of resolution loss in the finite antenna beamwidth. The processing done on the raw radar data to create the effects of the antenna with smaller beamwidth is termed as Beam sharpening. Let us consider y to be the magnitude of the received echoes, and Y to be the output of logarithmic amplifier.
The relation between y and Y is $Y = 100 \log_{10}(y)$.
Let x be the reflected signal, and A be the antenna beam pattern and we can express as

$y = Ax+n$ where n is the random noise. From y , we estimate the undistorted signal x with a finite impulse (FIR) filter F such that: $\hat{x} = Fy$ where F is a matrix and coefficients are to be calculated. FIR filter was applied to the transformed radar data y. The output data is subjected to nonlinear transformation to get back to original domain Final Image = 100 log10 (X). For each of the data frames, the video signal was digitized every 50ns for a total of 570 samples in range for each pulse. Multiple pulses were recorded at azimuth angle step; this allowed SNR and image quality improvement.

The noise in the radar imagery is suppressed by spatial and temporal filters. In this Beam sharpener approach FIR filter, it not only acts as a beam sharpener it also acts as a spatial noise suppressor. For reducing scintillation effect due to sequential radar imagery temporal filters are used. The other form of distortion in real time sequential processing is due to the motion of platform. In this system distortions due to scanned latency are much smaller compared to processing latency and the effect of the motion induced distortion is a smeared image. The difference between the true angle and the measured angle is called angular error. Using predictive filters these distortions are compensated.

The SVS Radar was tested and demonstrated successfully and the test data analysis indicated that the system provide adequate contrast between runway and surrounding grass/terrain, in all cases of weather, The system has an excellent performance under all conditions for which the human eye was inadequate.

V. Signal Processing in Synthetic Aperture Radar(SAR)

Digital processing has also permitted increased capability for extracting target information form the radar signal. High resolution SAR provides an image of a scene. Radars are used to recognize one type of target from another, with the aid of digital processing, inverse SAR (ISAR) produces an image of a target good enough to recognize from other classes of targets by extracting the spectrum of an target echo signal. Interferometric SAR, which uses two antennas spaced vertically with a common SAR system, can provide height information to obtain 3D image of a scene. Greater flexibility and real-time operation suggests digital signal processing in SAR.

SAR exploits the probability density of the clutter to detect man-made features by modeling the clutter by a family of densities and picking the density that best describes the clutter on a local basis.

Fourier based methods are used for detection of stationary and moving target detection and identification in reconnaissance SAR. The computational time of the Time domain correlator [TDC] is overcomed in the frequency domain. Here Digital spotlighting principle is used to extract the target's coherent SAR signature.

Step 1

Coherent matched-filtered SAR reconstruction of the scene in the presence of foliage is developed by exploiting the angle and frequency from the target's coherent SAR signature.

Step 2

With the help of Fourier-based method the three dimensional statistic representing the moving target coordinates and speed is used for moving target detection.

A. Strip Mapping SAR

On the incoming data, the pulse compression matched filtering is done to obtain Range resolution as discussed in previous chapter and stored prior to azimuth processing. Data are processed one row at a time to perform the azimuth compression, since large amount of data are collected large memory space is required. For each range resolution cell different azimuth compression filter is required.

Assuming range and azimuth resolutions are to be equal & total range is mapped to Δ_Z then each memory column has M samples and $2\lambda z_1 / L^2$ samples (nyquist rate sampling) in each row.

The total storage requirement is $Memory = \frac{2\Delta_z}{L} \bullet \frac{2\lambda R_{\max}}{L^2}$

Total calculation is that required for the operation of M azimuth pulse compression channels in parallel. So the total computational time using direct convolution is upper bounded by $\frac{2M\lambda R_{\max}}{L^2}$ multiplications.

By using FFT for high speed convolution together with parallel parallelism reduces the speed requirement significantly.

B. Spotlight mode SAR

Stretch Processing is adopted, i.e., the azimuth resolution is obtained from different Doppler shifts of the individual targets. Let x_1 and x_2 are the two targets both at same range z_1 then the received signal $r(t) = e^{-j\frac{\omega_o}{cz_1}(vt-x_1)^2} + e^{-j\frac{\omega_o}{cz_1}(vt-x_2)^2}$ is the sum of two chirps.

$1 + e^{-j\frac{\omega_o}{cz_1}\left[2(x_1-x_2)vt - x_2^2 - x_1^2\right]}$ will be the signal if x_1 is considered as a reference point and is called dechirping. The discrimination between the two targets are performed analyzing x_1 at zero frequency and target x_2 analyzed as frequency $2\omega_o v(x_1 - x_2)/cz_1$. Signal processing of the multiplier of dechirping and FFT is carried out. Since this approximation is done near to x_1 the FFT processing is limited to small region around the reference point. Also it is advantageous to bandlimit the dechirped azimuth signal to the frequency range of interest and do FFT. To avoid aliasing lowpass filter is chosen whose impulse response is a rectangular window and the frequency response is $\sin N\omega / N\sin\omega$. The high frequency-domain sidelobes of the rectangular window is overcome by using a different window or an optimal lowpass filter.

Thus this signal processing tends itself to a spotlight mode of SAR. Small areas of central reference point are imaged individually and a large map is constructed by piecing together several submaps.

The key feature to be considered to discriminate the man-made structure and the foliage is the characteristics the SAR signature of a man made metallic cylinder are different from the nature objects such as tree with the same size of low frequencies in the UHF band.

Why not Shape information to distinguish targets ?

The resolutions of the reconstructed SAR images are poor at UHF frequencies. The SAR magnitude reconstruction of both man-made targets and foliage will appear as blobs. Thus there is no much discrimination about the information.

By the process of Digital spotlighting the procedure to extract the coherent SAR signature of a target is done.

C. Target Detection and identification[2]

a. Matched Filter Reconstruction

Based on the SAR principles governing the variations of the gain and phase of target's coherent radar cross section with respect to the signal frequency and relative speed, angle, we a general expression for the two-dimensional matched filter that is capable of detecting a specified target in the presence of foliage.

The measured signal $S(k_u, \omega)$ is passed through a bank of N, two-dimensional matched filters, and it is passed through SAR wavefront reconstruction algorithm.

b. Digital Spotlight Detection and Identification

The image filtered reconstruction requires image formation for all possible target types followed by a search algorithm to detect the targets.

The targets are identified by search method, extract the coherent signatures, and then perform matched filtering on the signature of these suspected targets. The extraction of coherent signature from the coherent reconstructed image is done and process is called digital spotlighting.

Digital spotlighting is a computer based process that isolates the target or a target region in a SAR scene. To detect and identify targets, digital spotlighting the reconstructed image $f(x, y)$ is the reconstruction domain. A stationary target's signature is fairly focused and once the target signature is spotlighted, it is transformed into any domain of the SAR signal for identification.

D. Detection of Targets in Foliage

Three different target detection techniques for UHF SAR were discussed by Jeffry and his colleagues at Lincoln laboratory[7]. The se techniques are briefed out

a. BASELINE Approach

It consists of 3 stages with high resolution, Ka-band SAR DATA. The first stage, a simple two-parameter constant false alarm rate [CFAR] detector, is a computationally simple prescreening algorithm that rejects most natural clutter. A target detection is declared if the CFAR algorithm evaluation ratio exceeds CFAR threshold. This algorithm is followed by a clustering algorithm, which combines multiple detections occurring in a target-sized area into a single detection. The combination of these two algorithms is considered to be the baseline algorithm.

b. ADAPTIVE CHANGE DETECTION

The adaptive filters used are two-dimensional extensions of Widrow Least mean Squares [LMS]filter, used as a joint process estimators for noise cancellation. Each makes use of two images, a primary, D [presumed to have targets] and a reference X [without targets].

The clutter of the reference image is convolved with a weight matrix, W, to predict the corresponding clutter in the primary image. This primary image is subtracted from the primary to yield an error image, and the difference is used to adoptively tune each element of the weigh matrix by an approximation. At each iteration, the sign of the gradient is measured. After consecutive sign changes, and scaling, the deviation is found. By using two-pass change detection with the adaptive filters, the target-to-clutter ratio is increased.

c. MULTIPLE APERTURE DETECTION

It takes advantage of both the UHF SAR and the angular diversity of target returns. In order to achieve a high cross range resolution with a SAR operating at FOPEAN frequencies, it is necessary to process the data over a large integration angle. By splitting the integration aperture, multiple images are formed. It is then applied to two-dimensional adaptive filters used for change detection to these multiple images. This had an advantage with the different responses of clutter and targets with aspect angle. Clutter returns were expected to show less aspect angle dependency than targets, this property allows angle dependency than targets, and clutter can be removed by change detection algorithms. This technique has two distinct advantages over traditional change detection 1] the multiple aperture targets are perfectly co-registered and 2] only one flight pass is required over a given scene.

6 Conclusions

In this report a brief overview of applications of digital signal processing in Radar is presented. Matched filter implementation, echo cancellers and automatic detection and tracking are discussed in separate sections. In most of the modeling, Fast Fourier transform is a very commonly used technique for analyzing and filtering digital signals. Also a case study is carried out on Radar Synthetic Vision System for Adverse Weather Aircraft Landing. Different techniques of detection of targets in foliage are discussed for SAR. The recent advances in signal processing are blended with many more algorithms to present an up-to-date perspective and can be implemented in Digital Signal Processor because of their flexibility and the ability to attain high precisions.

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References:

[1] Firooz Sadjadi, Mike Helgenson, Jeff Radke, Gunter Stein, " Radar Synthetic vision system for Adverse Weather Aircraft Landing", *IEEE Transactions on Aerospace and Electronic Systems*," Jan 1999, Vol 35, No.1, pp2-15.

[2] Mehradad Soumekh, "Reconnaisance with Ultra UHF Snythetic Aperture Radar", *IEEE Signal Processing Magazine,* July 1995*,* Vol12, No.4, pp 21-39.

[3] P.E.Blankenship and E.M.Hofstetter, " Digital Pulse Compression via Fast convolution", *IEEE Transactions Acoustic Speech and Signal Processing*, Volume ASSP-23, April 1975, pp 1898-201.

[4] W.M. Brown and L.J.Porcello, "An introduction to Synthetic Aperture Radar", *IEEE Spect.,* Sep1969*,* pp 952-62.

[5] Lawrence R. Rabiner and Bernard Gold, " Theory and Applications of Digital Signal Processing", Prentice Hall, INC

[6] Alan V. Oppenheim, " Applications of Digital Signal Processing", Prentice Hall, INC

[7] Jeffrey G, Nanis, " Adaptive Filters for Detection of targets in Foilage", *IEEE AES Systems magazine*, Aug 1995, pp34-37.

[8] Eaves Reedy, "Principles of Modern Radar",