Synthetic Aperture Radar For Motor Vehicles

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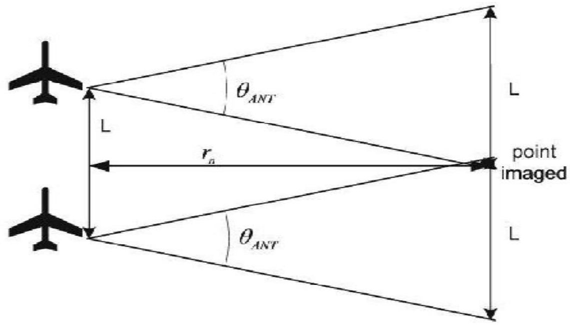
Abstract- *Our project is to make and SAR(Synthetic Aperture Radar) base automatic system for Motor vehicle to increase road safety around Cities during winter season. In this paper we are focusing on the SAR technology and the methods of using it in motor vehicles. Because the fog become very thick so even the fog light become ineffective because it can't penetrate through the dense fog. As the media reports says the NCR region is the most dangerous region in India as far as road safety is concern ,and it becomes even more dangerous in winter because of the foggy weather and 0 visibility due to foggy weather. There are more road accidents in NCR region I India than any part of country in winter. So we decided use SAR technology to make a spatial images of front road view and detect the objects and make their images on home screen in the vehicle , so the driver can see a better view of road and manage the vehicle accordingly. This device will help the to improve the diving conditions for the public and will help to minimize the road accidents and will assist the drivers.*

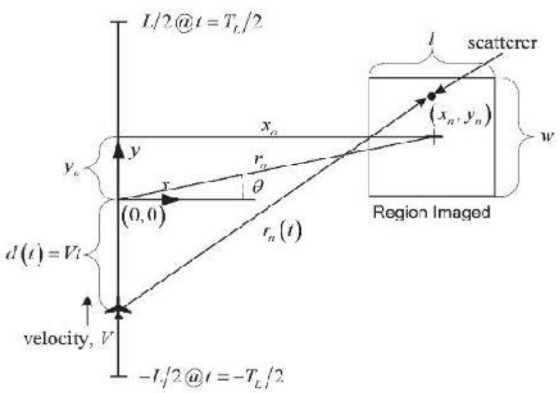
Keywords- SAR, Fast Faurier Transform, Azimuth FFT, Dopler

I. INTRODUCTION

As we know that there are number of road accidents around world in winter season because of fog which covers the whole landscape and the visibility becomes zero. The fog around cities become very dense to penetrate because of the air pollution around cities so even the use of fog lights are not enough to see through it. So we decided to look for a technology which can be use in motor vehicles so we can see through the fog what's coming to us while we are driving. Synthetic Aperture Radar (SAR) systems are all weather, night and day, imaging systems. [1] SAR is usually implemented by mounting a single beam-forming antenna on a moving platform such as an aircraft or spacecraft, from which a target scene is repeatedly illuminated with pulses of radio waves at wavelengths anywhere from ammeter down to millimeters. The many echo waveforms received successively at different antenna positions are detected and stored and then post-processed together to resolve elements in an image of the target region. SAR is applied widely in many areas such as military, agriculture and ocean. The figure.1 shows the resolution limit of strip map SAR. The speckle noise in SAR images can be removed using an image restoration technique called despeckling. In statistical image processing an image can be viewed as the realization of a joint probability density function..The central idea of SAR processing is based upon matched filtering of the received signal in both the range and azimuth directions. Matched filtering is possible because the acquired SAR data modulated in these directions with appropriate phase functions. The modulation in range is provided by the phase encoding of transmitted pulse, while the modulation in azimuth is created by the motion in the signal. The point targets are arrayed in Cartesian type coordinate system space defined by range, azimuth, and altitude as analogs of x, y and z directions. The figure.2 shows the cross range imaging geometry. The transmitted radar signal x(t), is assumed to be a chirp pulse (linearly frequency modulated signal) given by rec cosfKt where f0=9.36GHz, pulse duration Tr=25µs, (frequency bandwidth of the chirp=300MHz), Kr is the range of the FM rate, measured MHz/ µs. The transmitted radar signal as a course with a linearly ramping up frequency over a transmit duration followed by a null duration. The transmit window is called the pulse envelope, and defines the duration of the transmission. During the receive duration, the antenna waits to receive reflected radar signals from the targets contained in a one dimensional transmit and receive duration is called the pulse repetition frequency, PRF, and defines the amount of pulses transmitted per second. The chirp signal is complex and has complex envelope g(t)x(t)=g(t)exp(j2πf0τ) Let point scatterer has a dimension, smaller than the wavelength =c/v0 be located at a distance R-range away from the radar. The radar platform has a velocity v. The point is seen at the evaluation angle and azimuth angle from the antenna main pointing direction. The received echo is proportional to the transmitted wave and delayed by the range slice echo as function of quick time. One over the combined round-trip delay 2R/C, In the receiver the echo signal is coherently demodulated i.e. carrier frequency is removed, resulting echo signal of the pointer scatterer. The phase term depends on R, governs the interference of echoes from different scatterers. The shape of the pulse envelope g(τ) determines the range resolution of the radar, it is the ability of radar to distinguish two scatterers at slightly different ranges. g(τ)= sinc(τ B) The achievable range resolution is defined as half power width of g(τ). The chirp functions can be compressed to a sinc function by correlation with a chirp function with the same frequency rate, thus leading to the resolution.



[1]Figure.1 Resolution limit of Stripmap SAR



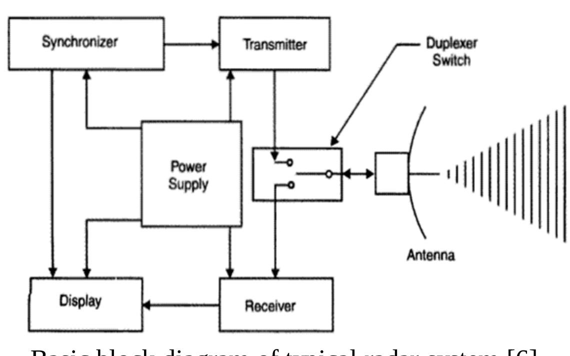
[1] Figure2. Cross range imaging Geometry

II. PRINCIPLES OF SAR

Introduction

RADAR is an acronym for Radio Detection And Ranging. Radar works like a flash camera but at radio frequency. Typical radar system consists of transmitter, switch, antenna, receiver and data recorder. The transmitter generates a high power of electromagnetic wave at radio wavelengths. The switch directed the pulse to antenna and returned echo to receiver. The antenna transmitted the EM pulse towards the area to be imaged and collects returned echoes.

The returned signal is converted to digital number by the receiver and the function of the data recorder is to store data values for later processing and display.



Basic block diagram of typical radar system.[6]

The radar platform flies along the track direction at constant velocity. For real array imaging radar, its long antenna produces a fan beam illuminating the ground below. The along tracker solution is determined by the beam width while the across resolution is determined by the pulse length. The larger the antenna, the finer the detail the Radar can resolve. In SAR, forward motion of actual antenna is used to 'synthesize' a very long antenna. At each position a pulse is transmitted, the return echoes pass through the receiver and recorded in an 'echo store'. The Doppler frequency variation for each point on the ground is unique signature. SAR processing involves matching the Doppler frequency variations and demodulating by adjusting the frequency variation in the return echoes from each point on the ground. Result of this matched filter is a high-resolution image.

Sar Focusing

The focus was on improving the computational efficiency and accuracy of the SAR simulation so that it could be applied to more complex, time-sensitive two dimensional targets . All these simulations can be roughly categorized into three groups. The first group works in time domain. It creates a high-precision raw data set. However, this method has low computational efficiency. The second group concentrates on the raw data generation of extended scenes that operates in the two-dimensional frequency domain. The third group can simulate SAR raw data by using inverse imaging algorithm in hybrid domain. The SAR system is conventional pulsed radar, which takes advantage of the relative motion between the sensor and target to synthesize a very long antenna and to achieve a high cross-range (azimuth) resolution. Each echo retains both its amplitude and its phase. It is usual to adopt the complex envelope representation in which the received signal is complex, with its real and imaginary parts obtained through quadrature demodulation from the incoming band pass signal. This means the trajectory migrates through rangecells during the exposure time of the target in signal memory; hence, the name "Range Cell Migration" or RCM. This migration complicates the processing, but ironically, it is an essential feature of SAR. This variation of slant range with time imposes an FM characteristic on the signal in azimuth direction. The hyperbolic form of the slant range equation can be expanded in a power series, resulting in a linear RCM component. A quadrature RCM component and higher order terms. The first generation of satellite SAR processors used the power series expansion of the range equation in the time domain and the range Doppler domain. Later it was discovered that the hyperbolic form could be kept in all domains, thereby improving the processing accuracy, however, the power series expansion is sometimes useful for analysis purposes. The range Doppler algorithm was the first algorithm developed for civilian SAR satellite processing. It is still the most widely used algorithm because of its favorable trade-off between maturity, simplicity, efficiency and accuracy. However, under certain conditions, its two disadvantages can become apparent. First, a high computing load is experienced when a long kennel is used to obtain high accuracy in the RCM Correction (RCMC) operation. Second, it is not easy to incorporate the azimuth frequency dependence of SRC, which can limit its accuracy in certain high squint and wide-aperture cases? A chirp is a signal in which the frequency increases (up-chirp) or decreases (down-chirp) with time. The chirp-scaling algorithm was developed specifically to eliminate the interpolator used for RCMC. It is based on scaling principle whereby a frequency modulation is applied to a chirp encoded signal to achieve a shift or scaling of the signal. Using this chirp-scaling principle, the required range-variant RCMC shift can be implemented by using phase multiples instead of a time-domain interpolator. The algorithm has the additional benefit Secondary Range Compression (SRC) can be made in azimuth frequency dependent.

This benefit arises because the data available in two-dimensional frequency domain at a convenient stage in the processing. This "chip scaling" principle, the required range variant RCMC shift can be implemented; using phase multiples instead of a time domain interpolator.

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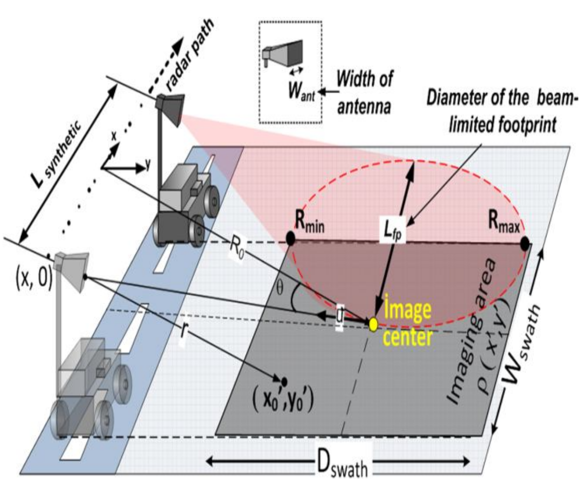


[Working of radar system in vehicle][7]

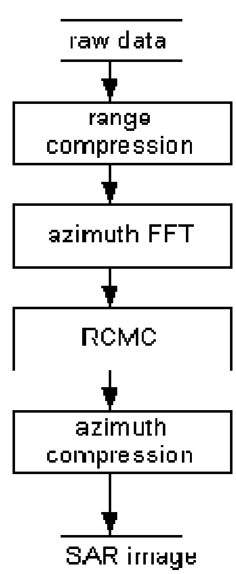
By using Chirp Scaling principle, linear FM signal multiplied by correlated FM signal (CS factor), and result is still a FM signal, only the phase center and the frequency modulation rate changes. After range is compressed with new FM rate, displacement occurs at the location of the signal, which makes target range curvature in frequency domain that has the same shape in different range. This is the purpose of chirp scaling equalize all the range migration trajectories to a reference range.

III. SAR PROCESSING

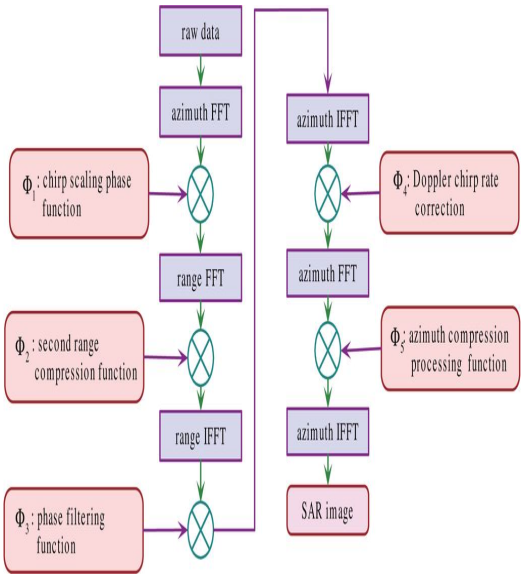
[2]The main goal of SAR data processing is the determination of the range and azimuth coordinates of the targets lying in the strip-map.

The SAR data space is a conceptual collection of SAR data arranged by range line (1, 2, 3, 4, . . .) with the first data point from each range line at the top and the last data from each range line at the bottom . A range line is a recording of all the reflections from a single transmitted chirp pulse.
Generally there are two approaches for SAR processing, mainly.Two-dimension Algorithm and Range Doppler Processing Algorithm. Two-dimension Algorithm processes the range and azimuth data simultaneous whereas the Range Doppler Processing algorithm implements range compression processing followed by azimuth compression processing. However, Two-dimension Algorithm proposed by Alan Di Cenzo required larger memory and computational power. The most common algorithm employed in most the SAR processing system is the Range Doppler Processing algorithm. It is a two-dimensional correlating procedure. The two dimensions of the correlation processing are realized as two one-dimensional matched filter operations namely range compression and azimuth compression.

The first matched filtering operates on the single pulse radar returns and the second matched filtering operation operates on the Doppler signal.



{Concept of SAR processing}[4]



{Range Doppler Processing}[5]

[4]ange Compression- In collecting the SAR data, a long-duration linear FM pulse is transmitted. This allows the pulse energy to be transmitted with a lower peak power. The linear FM pulse has the property that, when filtered with a matched filter, the result is a narrow pulse in which all the pulse energy has been collected to the peak value. Thus, when a matched filter is applied to the received echo, it is as if a narrow pulse were transmitted, with its corresponding range resolution and signal-to-noise ratio. This matched filtering of the received echo is called range compression. Range compression is performed on each range line of SAR data, and can be done efficiently by the use of the Fast Fourier Transform (FFT). The frequency domain range matched filter needs to be generated only once, and it is applied to each range line. The range matched filter may be computed or generated from a replica of the transmitted pulse. In addition, the range matched filter frequency response typically includes an amplitude weighting to control sidelobes in the range impulse response. The steps in range compression for each range line are:

[4]Range FFT: For most products, the range line is divided into two overlapping segments, and an FFT is taken of each segment. The amount of overlap corresponds to the length of the transmitted pulse.

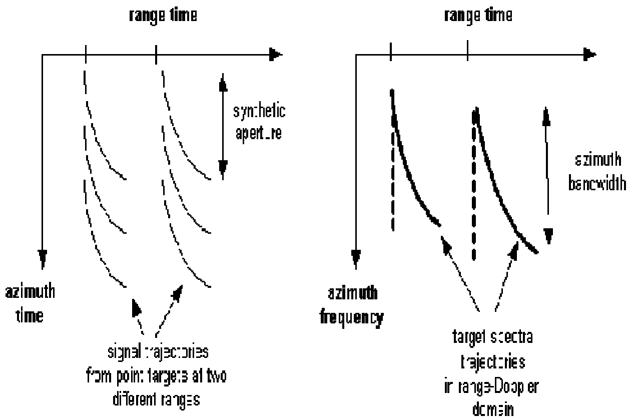
[4]Range matched (MF) multiply: Each FFT'd segment is multiplied by the frequency response of the matched filter.

[4]Range Inverse FFT: An inverse FFT is applied to each segment to get the range compressed data. Part of each segment is thrown away since the compressed range data is shorter than the uncompressed range data by the length of the transmitted pulse. The range matched filter is designed so that the throw-away is at the end of the data after the inverse FFT. The results from each segment are then joined together to get the compressed data for the whole range line.

[4]Range dependent gain correction: The range compressed data is multiplied by a vector that corrects the effects due to elevation beam pattern and range spreading loss.

[4]Azimuth FFT-An FFT is performed in the azimuth direction on each range gate to transform the data into the range Doppler domain. The FFTs are performed on blocks of data overlapped by the azimuth matched filter length. The range compressed data is stored in range line order. A group FFT algorithm is used which allows azimuth FFTs to be performed while still accessing the data in range line order. Thus the corner turn (transpose to azimuth line order) operation can be delayed until after RCMC.

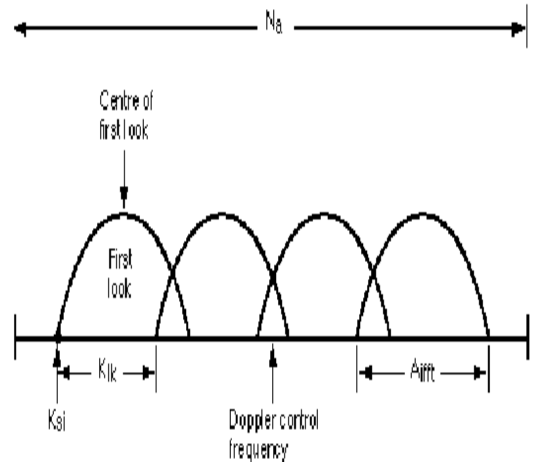
[4]Range Cell Migration Correction (RCMC)-After range compression, the signal energy from a point target follows a trajectory in the two-dimensional SAR data, that depends on the changing range delay to the target as it passes through the antenna beam. This trajectory may cross several range bins. In order to capture all the signal energy for azimuth compression, the signal energy from a point target must be aligned in a signal range bin. RCMC is the step of correcting for the changing range delay to a point target as the target passes through the antenna beam (range migration). For a given target, this range depends on the closest approach range from the satellite to the target (zero-Doppler range), and on the angle from the satellite to the target, relative to the broadside (zero-Doppler) direction. As targets at the same closest approach range pass through the antenna beam, they all traverse the same interval of angles, and so have the same variation in range from the radar. That is, the signal trajectories from targets at the same closest approach range have the same shape, but are displaced in azimuth because of the different target positions. Because of the relationship between the satellite-to-target angle and Doppler frequency, the range migration of all targets at the same closest approach range can be expressed as a function of Doppler frequency. That is, all signal energy from targets at the same closest approach range is collected into the same trajectory in the range-Doppler domain. This allows RCMC to be performed very efficiently in the range-Doppler domain. The shift in range that is needed to align the signal trajectory in a single range bin is determined for each azimuth frequency bin. This shift is then implemented by an interpolation in the range direction. The straightened trajectories are shown by the dotted lines in the figure. Other steps in SAR processing that require interpolation in range are slant range to ground range conversion (SR/GR), which converts the distance from the radar (slant range) to distance along the ground, and the range resampling to a desired output pixel spacing. For maximum efficiency, all of these range interpolations are combined into one operation.



[illustration of trajectories in time domain and range-Doppler domain][4]

[4]Azimuth Compression

Azimuth compression is a matched filtering of the azimuth signal, performed efficiently using FFT's. Note that the azimuth FFT has already been performed at this point. The azimuth FFT's were performed on blocks of data that overlap in azimuth by the matched filter length. The reason for the overlap is the throw-away after azimuth compression. The frequency response of the azimuth compression filter is precomputed using the orbital geometry. The azimuth filter also depends on range. Thus the data is divided into range invariance regions, and the same basic matched filter is used over a range interval called the FM rate invariance region. The size of this invariance region must not be large enough to cause severe broadening in the compressed image. Also included is an amplitude weighting to control sidelobes in the azimuth impulse response. Note that the position of the amplitude weighting in the azimuth frequency array depends on the Doppler centroid, which also depends on range. The way the azimuth compression is implemented depends on the type of image product. For single look complex products (IMS and APS), a single portion of the azimuth bandwidth is multiplied by the azimuth matched filter frequency response, and an inverse FFT is taken of the entire frequency array. The output is complex valued and left at the natural pixel spacing. For magnitude image products (IMP and IMG), a technique called multilooking is used to reduce speckle noise. In this case, the azimuth frequency spectrum is divided into several portions called looks. The part of the azimuth frequency array for each look is extracted, multiplied by the azimuth matched filter frequency response, and the inverse FFT is performed. The magnitude (detected) look images are then averaged to reduce speckle. This is described in more detail as follows. The extraction of the looks from the frequency array is illustrated in the figure below. The looks are positioned symmetrically around the Doppler centroid frequency. As the Doppler centroid frequency varies with range, the look frequency positions are different for different range cells. In practice, they are kept constant within the look frequency position invariance region.



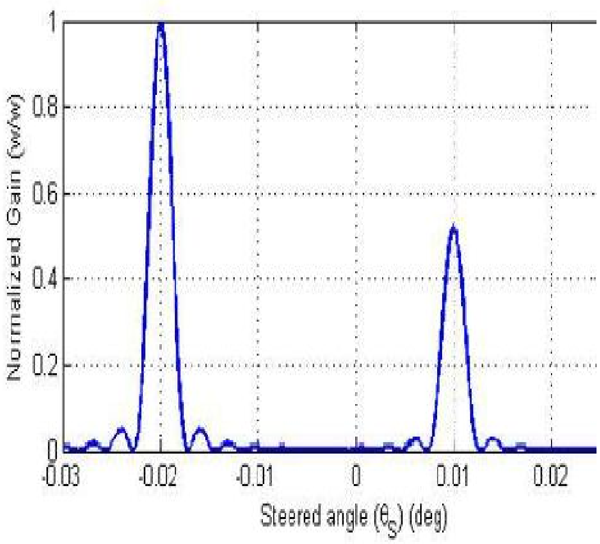
[Look Position Parameters][4]

The extracted frequency array for each look is multiplied by the matched filter frequency response and the inverse FFT is performed to form the complex look image. The matched filter frequency response is adjusted by a small linear phase ramp for each look. This is equivalent to shifting the compressed look in time, and is required to ensure that the images from different looks are aligned properly for look summation. The amount of azimuth shift is range-dependent. In addition, azimuth interpolation may also performed after look compression to achieve a desire azimuth pixel spacing, and it is done on each look separately. After look compression, each of the look images is detected. That is, the power of each complex sample is calculated. The detected azimuth looks are then summed, and the square root of the result is calculated to convert to magnitude. Finally, for the IMG product, the multilooked image is geocoded. This is a two dimensional resampling operation to convert the image to a desired map projection.

IV. SAR SIMULATION

[1]The simulation is the simulated received signal before any processing with exception of the down-converter. It also plays a significant role in studies concerning noise and clutter rejection and contributes toward optimizing SAR system parameters. To simulate SAR raw data, a chip Scaling method is used. This method first stretches the input surface reflectivity of the target in the azimuth and range direction

respectively. Then it derives the raw data by inverse equalizing the signal based on CS principle. This method avoids the time-domain integral operation and improves the computational efficiency. The platform in this simulation is an antenna attached to a plane travelling at an orbital velocity, along the azimuth direction and at the midpoint in the flight, the distance to the target equals the range of closest approach or minimum range to target.



Normalized radiation pattern vs. Beam steering angle-Two targets located at -0.02 and 0.01deg[1]

V. CONCLUSION

So as we see in this paper that the SAR can produce high resolution images of selected area so in my opinion we can use this technology in motor vehicles after few modifications to increase the road safety during foggy weather. Because the SAR operation requires the relative velocity between target and source so it will be more effective on the highways.

After looking all the concepts and references I am fully asuure that this technology can be very useful as a safety equipment for motor vehicles and this technology has a very big market scope to look for because of it's utility safe driving. So it will be one of the best upcoming application in automobile industry.

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