ISSN 2348-1196 (print)
International Journal of Computer Science and Information Technology Research ISSN 2348-120X (online)
Vol. 10, Issue 4, pp: (69-85), Month: October - December 2022, Available at: www.researchpublish.com

A Review on SAR Imaging Techniques for Low RCS Targets

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DOI: https://doi.org/10.5281/zenodo.7485765

Published Date: 27-December-2022

Abstract: **The method known as synthetic aperture radar (SAR) is utilized for creating high-resolution photographs stationary scenes. SAR is an imaging radar framed on a moving platform. In radar signal processing discovery of a weakly observable target is one of the most interesting area. In this survey, we will discussabout radar systems. Typical applications of radar include synthetic aperture radar, military application, airborne and spaceborne operation, speed control, air traffic control, and remote sensing. We also study about various imaging techniques that are used. Finally, potential applications of SAR imaging techniques.**

Keywords: **SAR, detection, observable target, imaging techniques, radar system.**

1. INTRODUCTION

The electromagnetic detection technology known as RADAR, or in order to function, radio detection and ranging emits electromagnetic waves and then observing the reflected waves. Range, angle, andvelocity of targets are all determined via radar. Detection shows whether or not the target is present [1]. Thetarget could be either fixed or mobile when the target is stationary, SAR method is employed when the target is not stationary, ISAR is utilized [2]. Ranging shows the separation between the item and the RADAR. Radar can be divided into two categories both activeand passive radar are used. An antenna transmits high-frequency radio waves onto the surface of the earth in active radar, which then collects information from the object's backscattered radio waves. Mono-static radars fall under this category [3-6]. The transmitter and the receptor are in the same place in this [6]. The transmitter and the receptor are located in distinct places in a passive radar system. The signalpropagating from a different point is what a passive radar system relies on [7-9]. Bi-static radar is the name given to this type target with a low RCS can be manipulated remotely, usesaerodynamic forces to produce lift, and does not require a human operator [10]. The low RCS targets have more widespread uses in both the military and public spheres. Warfare and spying are just two of the many militaries uses for low RCS targets [11-12]. The civil applications cover things like mountain mapping and other things [13]. The region absorbing the energy that generates in all directions is referred to as the targets RCS (rho) [14]. Low rcs target or small target refers to a target with RCS of under one square meter [15]. Due to its ability to carry explosives, an undefinable low-RCS target at the border might threaten national security by gathering important information and destroying material. An active sensor is largelyresponsible for finding low RCS targets [16-18].

2. RADAR SYSTEMS

Depending on the sort of signal a radar could process, the following two categories can be used to categorise radar [19].

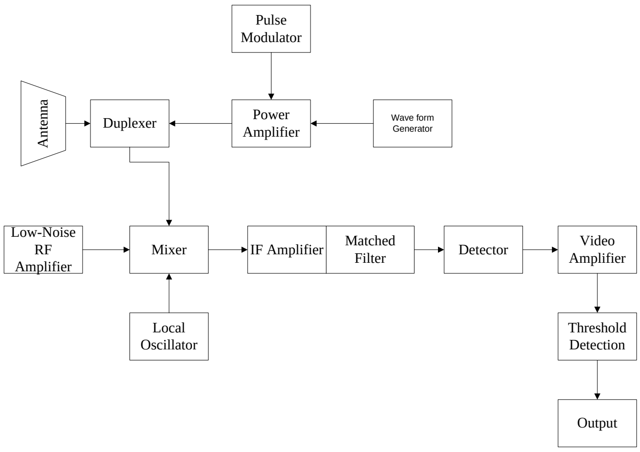

Fig. 1 Block Diagram of Pulse Radar on High power

2.1 Pulse Radar

Radar that employs pulse signals to find stationary objects is known as the simple or fundamental pulse radar [20-22]. It uses a single antenna to broadcast and receive signals and a duplexer to do so. The antenna will transmit a pulse signal with each tick of the clock [23]. The time gap that involves the two clock pulsations must be carefully choose to ensure that the present clock pulsations associated echo signal must be obtained prior the subsequent clock pulsations, it is crucial to set the time gap between the two clock pulses [24]. Moving Targets indication Radar is the name of the radar that use pulse signal to find non-stationary objects [25]. It is also known as MTI Radar or just MTI Radar [26]. It makes use of duplexer to transmit and receive signals using a single antenna [27]. MTI Radar uses the Doppler effects hypothesis to distinguish between stationary and non-stationary objects [29].

2.2 CW Radar

The term “continuous wave radar” speaks more about a particular kind of operational radar by using a continuous signal or wave .in order to track moving targets they use the doppler effect [30-33].

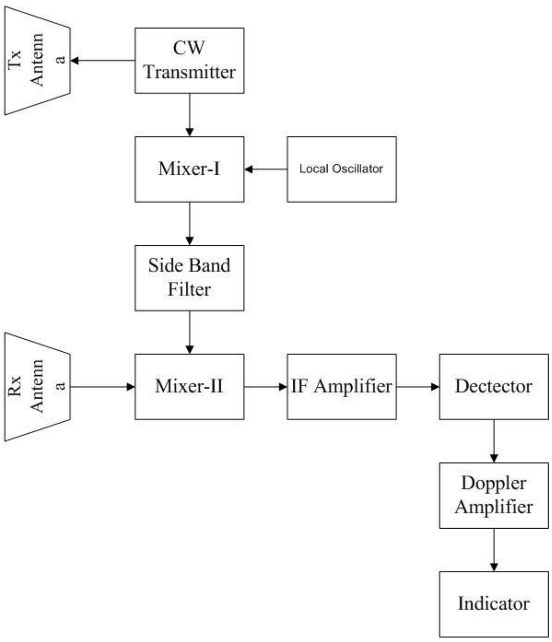

Fig.2. Block Diagram of Continuous Wave Radar

It is possible to discriminate between these two CW radar types they are

2.2.1 Continuous wave radar without modulated

Unmodulated CW Radar for short, is a radar type that uses a constant signal (wave) to identify moving targets. It also goes by the name CW Doppler Radar [34]. Two antennas are needed for this radar [35]. Wherein One of these two antennas serve as a signal transmitter, second antenna is utilised in signal reception [36]. Target distance from the radar is not measured only the target's speed is measured.

2.2.2 FMCW RADAR

FMCW Radar (Linear Frequency-Modulated Continuous-Wave) is the name given to CW Doppler Radar if it employs linear frequency modulation [37-39]. It is also referred to as FMCW, or frequency-modulated continuous-wave radar [40]. Two antennas are needed for this radar. Wherein one antenna serves in signal transmission, the second antenna is utilised in signal reception [41]. Along with the target's speed, it also calculates at what distance target is from the radar [42]. Among the several types of radar, tracking radar tracks the movement of one or more targets. Before it begins thetracking activity, it typically carries out the following tasks [43-45].

- Determining the doppler frequency shift.
- Determining angle of elevation and azimuth.
- Target recognition.
- The targets range.

3. SAR TARGET DETECTION METHODS

3.1 Target Detection in Multi-static

The raw radar data that was available at the sensor's output was used for the detection [46]. The HMM's fundamental premise that samples of data may be accurately described as random processes with parameters, also it is possible to estimate the stochastic process's parameters within a clearly definedframework [47] the process of simultaneously estimating position of the target and speed utilizing a functioningradar network and maximum search. This maxima search does not require data association because itoperates directly in the position-velocity space [49-52]. However, there is generally no assurance that the maxima will always match real aims. Using numerous dispersed radar systems, Feng et al [53-54] examined two non-growing characteristics in Cramer-Rao low bound target finding. They suggested a quick and effective power allocation approach for multiple cognitively dispersed radar system that heavily relies on alternating global search algorithm [55-58]. It was found that replacing one expensive high-power transmitter with multiple cheaper ones can save money without sacrificing radar performance [59] An unambiguous transmission from the transmitter and dispersed signal by surroundings both are obtained by the recipient [60]. It is possible to determine the position and velocityof any specific target by combining the data from various sensors. EL-Kamchouchy et al. suggested system architecture for multistatic s-band radar in order to locate and trace stealthy aircraft and tiny cross-sectional area aircraft [61-63]. The suggested geometrical configuration was tested with varied radar spacing in order to broaden the detection range of the air surveillance monostatic radar [64]. Also, to ascertain the improvement brought about by deploying this sort of radar, all practical stealthy aircraft paths were used to analyse the radar detection coverage [65]. The creators suggested two multistatic radar system configuration of S-band radar that would extend its detecting range of tiny covert aircraft [66]. The optimal receiver In case of a multistatic radar system is created by synthesizing target echoes with Rayleigh fluctuation and gaussian noise [67]. Baumgarten looked at how well this receiver performed and showed that under some circumstances, multistatic systems target detection skills are comparable to any of the monostatic system [68-70]. The intrinsic multistatic structures complexity may be diminished via using more direct approach, such as making a number of ancillary judgements at as many conventional receivers as feasible. A key analysis based upon an OR-criterion would then be made. In their work, D'Addio et al. found the best structures for receiving, detecting targets by centrally processing various radar data obtained from local sensors [71-72]. In-area sensors an analytical study of the model results in a unified optimum receiver for signals changing in accordance with the swerling I, II, III & IV models. Chaitanya et.al suggested a most common technique that may be used with basic DPCA cancellation in order to lessen the leftover of clutter at the output. By reducing clutter spectral breadth, the displaced phase centered antenna (DPCA) increases the likelihood of detecting slow-moving targets [73]. A model created by Counts et al. uses calibrated measured data to exclude cable effects and direct coupling inside the system. Images created by beam formation algorithm gives a bit perception onto how well this data was acquired [74-76].

3.2 Target Detection using Multi-static Radar

In addition to the evolution of the problem with radar detection to a compound-Gaussian situation with theGLRT detection, Reddy et al. provided numerically new optimized process of a polyphase coded waveform for orthogonal MIMO radar. The Particle Swarm Optimization Algorithm optimizes the transmitted orthogonal waveforms (PSO) [77]. Polarimetric radar systems send data using polarized waveforms that can mimic targets scattering patterns. The advantage of this technology can only be used to their fullest extent when the type targets is correctly identified, which can be costly [78]. Gogineni et al. presented distributed MIMO (multiple input multiple output) radar as a method for locating the target. They used a game theoretic framework for choosing a transmitting polarization by analyzing how each feasible transmit scheme would affect the different accessible target profiles [80]. This approach, unlike conventional approaches, can be put into practice without incurring significant costs because it does not need extracting the precise desired attributes from the measured data. Haungetal resolved the target estimate difficulty in bi-static multiple-input, multiple-output (MIMO) radar by using low-rank tensor completion [81]. Even though only a fraction of the data was actually recorded in the beginning across multiple pulsation intervals, the characteristics of a thin target picture, specifically the direction of arrival and direction of departure, were calculated simultaneously in this technique [82]. To retrieve the missing 3-D data, a tensor rank reduction approach based on the accelerated proximal gradient line-search (APGL) was developed [83]. The suggested techniques link theDoppler frequencies to the targets by using estimates of the target's position, velocity, and direction, either segregate or all at once [84]. The predicted Doppler frequencies at each receiver are used to calculatethe number of targets in the first stage. Each target generates a unique set of Doppler frequencies for each receiver as a result of the MIMO arrangement and frequency-based nature. As a result, after a few rounds, the system can determine how many targets there are [85-87] Particularly for high Pd values, thesuggested data association algorithms can successfully match the Doppler frequencies with actual targets. Better results are obtained using the Direction Based Data Association (DBDA) method that combines a dynamic threshold (DBDA-DT) with target direction estimations [88-89]. It is crucial that these algorithms employ only two successive scans at a time rather than all previously recorded data and are independent of the goal motion parameters. Gassier et al researched and discussed the issue with moving target recognition with use of passive radar by using the DVB-T transmitters of chance in multipath environments [90]. Inconsistent correlators may be used to decrease the number of false alarms and the masking effect caused by zero Doppler contribution (ZDC) for these emissions [91].

3.3 Moving Target Detection Methods

The Discrete polynomial-phase transform (DPT) approach may be accustomed to recognize all echoes produced by an accelerating target at high SNR due to its minimal processing intricacy and excellent real-time performance. The DPT algorithm's drawback of this is because there is high mean square error of the frequency modulation rates, also a less detection probability when the SNR is low [92]. Pang et al. examinedthe causes of the DPT technique's performance detection degradation and presented an SDPTapproach that can enhance DPT performance detection in low SNR [93]. In this technique, the segmentedsignal is coherently accumulated to increase the input SNR before the frequency modulation rate parameter is estimated using the DPT approach [94]. Li et. al created two novel detectors based on the Rao and Wald criteria for adaptive MIMO radar detection of moving objects in diverse settings. First, the Rao and Wald tests were created along presumption that the goal velocity and clutter structure were known. By doing a numerical optimization with respect to the desired velocity, the test variables that emerge are then modified. Finally, an estimate obtained from secondary data is used to replace the clutter structure in the adaptive versions. Finally, Monte Carlo simulations are employed to gauge how well the proposed detectors function. Gennarelli et al recommended a passive multistatic through-wall radar system for determining where moving objects are located in three-dimensional(3-D) space. The localization job is performed using an inverse source-based method, and the unidentified targets are identified to be the source of contemporary distribution produced vs their size or surface [95]. To compensate for the single frequency receiver operation's lack of resolution, a multi array picture fusion approach is used. To locate and identify animated targets in the scene, change detectionis used. By lengthening the coherent integration time in airborne or spaceborne radar application, Huanget [96]. Al claim that the radars capacity to identify a weak navigational target may be increased. Coherent integration performance however, may be negatively impacted by complicated range migration (RM) and Doppler frequency migration (DFM) effects. For purpose of detecting as well as estimating the motion parameters of a weakly maneuvering target, the authors have taken into account. DFM and RM of third order [97]. A keystone transform is used as well as matching filtering process is carried out in azimuth-time and in the range-frequency domains, to obliterate any lingering coupled outcomes among azimuth and range [98]. Finally, clear picture of an object in motion is captured, as well as three parameters- velocity, acceleration, and acceleration rate are successfully determine. In order to get a near integration performance, the computational complexity must be reduced as the reduced parameter searching dimension. Results from simulated processing are offered to verify the viability of the suggested approach [99].

3.4 Detection of ground moving Targets

A new reduced-dimensional technique for GMTI clutter avoidance using joint pixels sum-difference data was proposed by Yang et al., who worked on multi-satellite radar system. The reduced dimensional joint pixels data are obtained by orthogonally projecting the combined pixels data obtained from several synthetic aperture radar (SAR) photographs created by a multi- satellite radar system [100]. According to statistical expectations, combined into from the pixels comprise that information is shared and unique among SAR images. Afterward, adaptive processing can accomplish the GMTI and clutter cancellation goals. Onthe basis of readings from radar for airborne ground moving targets, the discriminating a set tightly spaced targets significant difficulty tracking target on the ground. Based on simulation of both single and multi-target situations, Mertens et al. incorporated the carbonized probability hypothesis density filter into the Gaussian mixture. A modified matching technique was created by Xu et al. further to enhance the shadow-aided methods detecting performance. They also tried toproduce an effective multi-feature-based shadow detection technique [101]. Additionally, the efficiency of the suggested strategy to identify moving targets for a longer period of time has been validated by the simulated tests. The findings show that the shadow-aided approach outperforms the conventionalGLRT detector in terms of detection performance [102]. It is also demonstrated that the suggested shadow-aided approach has decreased & performance of detection in the high-SNR area. Ground-penetrating radar is employed by Giannakis et al. to determine a real-time estimate contrary to its landmine signal-to-clutter ratio (SCR) identification. An example of artificial neural networks used to represent SCR in relation to the characteristics of how deep the target is, center frequency of its pulse, and the depth of the soil.

4. IMAGING ALGORITHM

Imaging Techniques in SAR are as follows:

1. The Range-Doppler algorithm.
2. Chirp-Scaling Algorithm

4.1 Range Doppler Algorithm

The findings show that the shadow-aided approach outperforms the conventional GLRT detector in terms of detection performance. It is also demonstrated that suggested shadow-aided approach has decreased performance of detection in the high-SNR area. Ground-penetrating radar is employed by Giannakis et al. to determine the real-time estimate of its landmine signal-to-clutter ratio (SCR) identification. Simulated neural networks are used to represent SCR in relation to the characteristics how deep the target is, the depth of the soil, and the pulse's frequency in the Centre [103-105]. The most crucial component of this algorithm is RCMC. Range frequency and azimuth frequency domains are used for RCMC. It is knownas the Range Doppler Algorithm because azimuth frequency is impacted using the Doppler Effect or is linked to Doppler frequency. Three alternative approaches can be used to implement RDA [106]. However, they are all comparable in steps and only differently compress secondary range (SRC) RDA's primarysteps are:

1. First range compression
2. FFT for Azimuth
3. RCMC
4. Filtering by Azimuth
5. Reverse FFT
6. Image Synthesis

The most popular SAR processing technique that offers results with a respectable level of accuracy is the implementation range doppler algorithm [108].

RDA consists of these three steps:

1. Compression of the range
2. Correction of Range cell migration
3. Compression in the azimuth.

However, the specific steps required to implement the algorithm's code are as follows:

1. Specifying auxiliary information and parameters.
2. Data transformation to 2D frequency domain
3. Implementing a Match filter and Range Compression
4. Correcting Range Cell Migration
5. Transforming Range-Doppler domain from Range-Compressed data
6. Creating a Match filter and applying Azimuth compression
7. Sending data back to the time-domain
8. Results visualization.

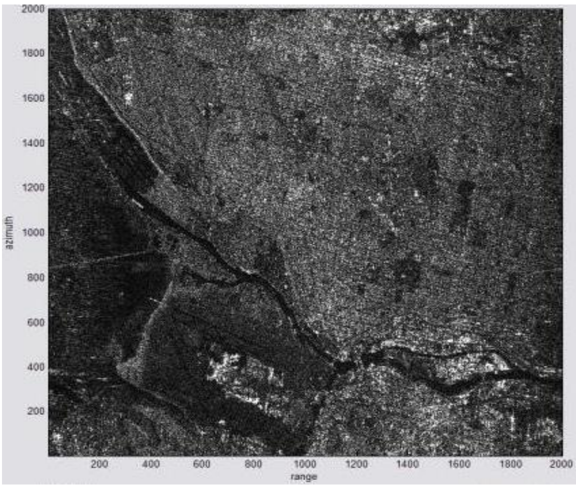

Fig. 3 A Processed and Improved Scene by employing RDA

4.2 Chirp-Scaling-Algorithm.

Chirp-Scaling Algorithm is abbreviated as CSA. It operates on the scaling principle where a chirp-encoded signal is subjected to frequency modulation induce the scaling or shifting of a signal, it was created expressly to replace the RCMC's interpolator [109]. The range migration of each target trajectory is compensated using chirp scaling, which employs a phase multiply. This approach holds the advantage of making the SRC dependent on azimuth frequency because the availability of the data is in the two-dimensional frequency domain [110]. The CSA's steps are:

1. Data is transformed to the range Doppler domain using azimuth FFT.
2. Using the Chirp Scaling
3. Data is transformed into a two-dimensional frequency domain using a Range FFT.
4. A phase multiply simultaneously uses RCMC, secondary range compression, and rangecompression.
5. Range IFFT that provides information in the range Doppler domain
6. A further phase multiplication uses a range-dependent matching filter to provide azimuthcompression.
7. Azimuth IFFT that returns data to the azimuth time domain is number seven.

5. SAR IMAGING MODES

There are numerous different imaging modes supported by the most recent SAR systems in addition to the simpler strip-map imaging mode that was previously provided. The antenna is separated into many sub-apertures to support these imaging modalities [111-113]. Each sub-phase apertures and amplitude canbe adjusted, which alters the antenna radiation pattern and, in turn, the illuminated area.

1. Strip-Map SAR.
2. Scan SAR
3. Spotlight SAR
4. High-Resolution Wide-Swath Imaging.

5.1 Strip-Map SAR

The strip-map SAR, which has been addressed in the previous sections, is the most common configuration. In this imaging mode the antenna patterns remain fixed and it illuminates a fixed swath as shown in Fig.4.The data acquisition occurs for a continuous strip of the terrain [114-115].

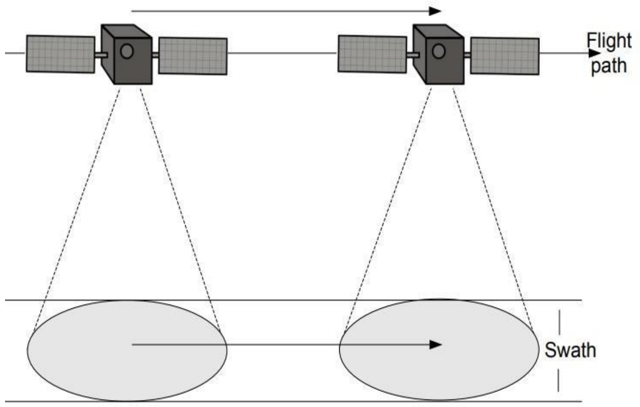

Fig. 4. Strip-Map SAR Imaging Mode

5.2 Scan SAR

The Scan SAR imaging mode is used when a wider swath is required. The Antenna pattern is steered in elevation during the data acquisition interval [116]. This leads the illumination of several sub-swaths as illustrated in Fig. 5 Since each sub-swath is illuminated during a fraction of time

When compared with the strip-map situation, the azimuth resolution is proportionally degraded [117].

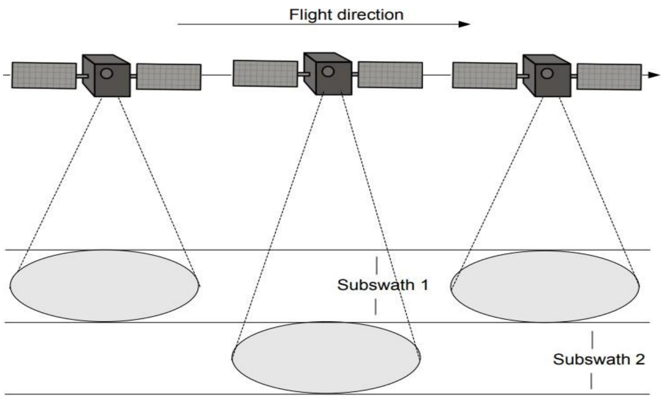

Fig. 5 Scan SAR Mode Increases the Swath Width at Expenses of Expenses of Azimuth Resolution.

5.3 Spotlight SAR

For a specific target region, the spotlight SAR imaging setup is employed to attain the best resolution as shown in Fig. 6 Increasing the integration time improves the resolution. In contrast to strip-map SAR operation, the antenna pattern is guided to illuminate a fixed region of interest for a significantly longer period of time. The decrease in photographing a continuous swath along [118-119].

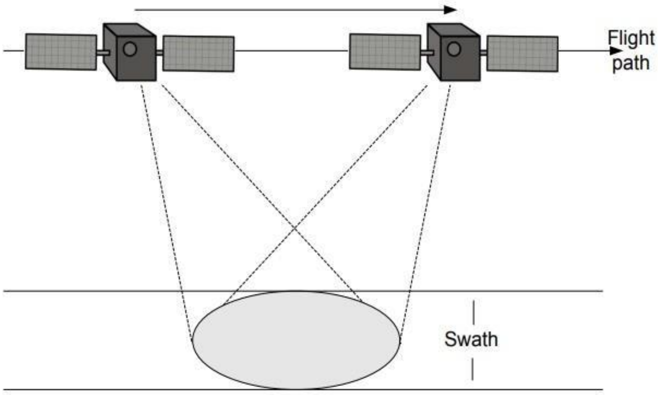

Fig. 6 Spotlight Mode: Increases the Azimuth Resolution having as Trade-off the Decreases of the swath

5.4 High- Resolution Wide-Swath Imaging

A unique imaging technique has been suggested to get over the trade-off restriction between azimuthresolution and spatial coverage. In this imaging technique, multiple apertures recording in azimuth iscombined with digital beamforming on receive in elevation. With this approach it is also getting excellent as illustrated in Fig. 7 Simultaneously Improves Azimuth Resolution and Swath Width at Expenses of Hardware and Computational Complexity. The drawback of Conventional SAR system is that they can only accomplish a large area at lower azimuth resolution. The relatively high Doppler centroid, which is one of the most critical factors that must be determined in order to compute SAR pictures is potential downside of multichannel Scan SAR approaches.

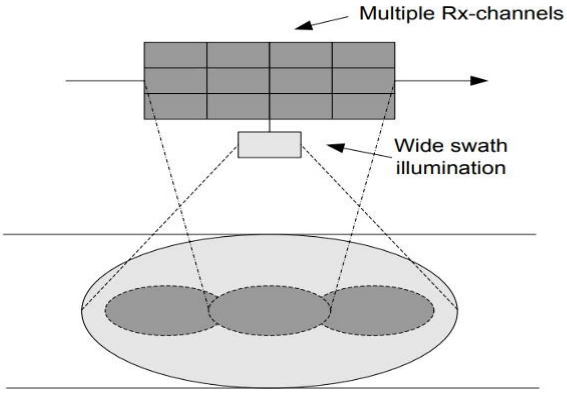

Fig. 7 High-Resolution Wide-Swath SAR

6. POTENTIAL APPLICATIONS OF SAR

Agriculture: Surface roughness variations are a sign of crop harvesting, soil tillage, and fieldploughing [123].

Floods: Surface reflection variations can be used to differentiate between heavy and minor flooding,metropolitan areas, and permanent bodies of water [124].

Land subsidence: it can be detected by differences in measurements over time, such as sinking groundbrought on by the extraction of subterranean natural resource [125].

Snow cover: By identifying wet, dry, and snow-free locations, variations in surface reflection can be used to forecast snowmelt [126].

Wildfires: Penetrating dense smoke can deliver more precise and fast information about the scope of aforest fire and help assess vegetation damage [127].

Wetlands: Where land is covered by shallow water, penetration through wetland areas might disclose flooded plants [128].

7. LIMITATION AND SCOPE OF SAR

The strategies presented here can be used to find a target in a variety of circumstances. Additionally, itexplains how various radar configurations can improve a target's detectability [129-132]. The majority of the methods increase computing complexity cubically as the number of transmitters increases, whereas theyincrease an NP problem's calculation volume exponentially [133-135]. The majority of the current radar algorithms replicate the environment (clutter) by assuming that it is stationary [136-137]. However, depending onthe context in which a radar is operated, the clutter's properties might really change greatly. The performance of the radar could be severely hampered if this non-stationary fluctuation is not considered [138-141]. Since they rise only a few meters above the water's surface, small targets (such small icebergs)are typically difficult for marine radar systems to detect [142-146]. Given that the typical RCS is low at surface marine debris, very high-resolution marine radars havethe potential to detect incredibly small targets [147-150]. The statistical features of marine debris change from being uncorrelated and Gaussian to correlated and strongly tailed, which is a significant negative [151]. When a target is far away, it is frequently noticed that some algorithmscannot differentiate the shape of the target [152].

8. CONCLUSION

The numerous target detection methods are discussed in this paper, along with their many benefits anduses. Numerous researchers have used many methods to try to tackle this issue using various strategies, but some other above techniques still have significant drawbacks, which are examined and signify the study field where a solution has not yet been found.

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