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Original Article

Study of synthetic aperture radar and automatic identification system for ship target detection

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Abstract

In the past, the main goals of Synthetic Aperture Radar (SAR) systems were the study of the interaction of electromagnetic waves with the earth surface. Recently, the development of multi-channel SAR systems has enabled the development of more sophisticated techniques for the surveillance activities. SAR is the most efficient instrument, which provides high-resolution data for wide ocean area surveillance under all weather conditions. The intrinsic capability of this instrument is to provide a quick view of the oceanic surface features such as vessels, waves and currents, oil spills, laver facilities and wind fields. The ship detection or recognition is achieved in two steps: the first step is to identify the target in SAR images of a busy traffic, which corresponds to Automatic Identification System (AIS) signals by the "dead-reckoning (DR) position", and the second step is to estimate the position, size and speed of the ship from SAR images and compare these results with the AIS "true" data. This paper presents the fundamentals of SAR and its integration with the AIS data for the ship target detection.

Keywords: SAR; AIS; Dead reckoning; Target detection.

1. Introduction

Ocean Environment Monitoring (OEM) has become one of the most important tasks now a day, which involves tracking and monitoring of illegal vessel activities, oil spills, retrieval of wave parameters, wind and current observations etc. Mapping and monitoring of these systems, features and activities require the wide area of imaging with high enough resolution. Many times the imagery must be acquired under various weather conditions or day as well as night. Space-borne remote sensing techniques have become the most cost effective research tools today for rapidly expanding ocean observation and surveillance tasks and requirements. The backscattering response of surface materials to illumination by microwave energy, also referred to a "backscattering signal", is very different from spectral reflectance of the visible sunlight of the same material [36]. Synthetic Aperture Radar (SAR), an active microwave sensor onboard either space-borne or air-borne, illuminates the target with a focused, directional beam of energy, producing unique scattering effect depending on the orientation of the sensed objects [10].

High resolution SAR is able to provide images of the two dimensional information objects on to the earth surface. A good radar image depends upon a smooth variation in phase history over the data-gathering interval. The high resolution and large spatial coverage of SAR imaging systems offers a unique opportunity to derive the various oceanic features [3]. SAR systems take an advantage of the long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics to provide high-resolution imagery [35]. SAR images are a relatively new data type requiring special interpretation techniques in order for users to utilize the data in most operational and reliable applications. These data have been widely used for fishing vessel detection, ship traffic monitoring, immigration control and other physical oceanographic applications [8,47].

With increasing worldwide world travel and transport of goods, vessel traffic services, ship routing and monitoring of

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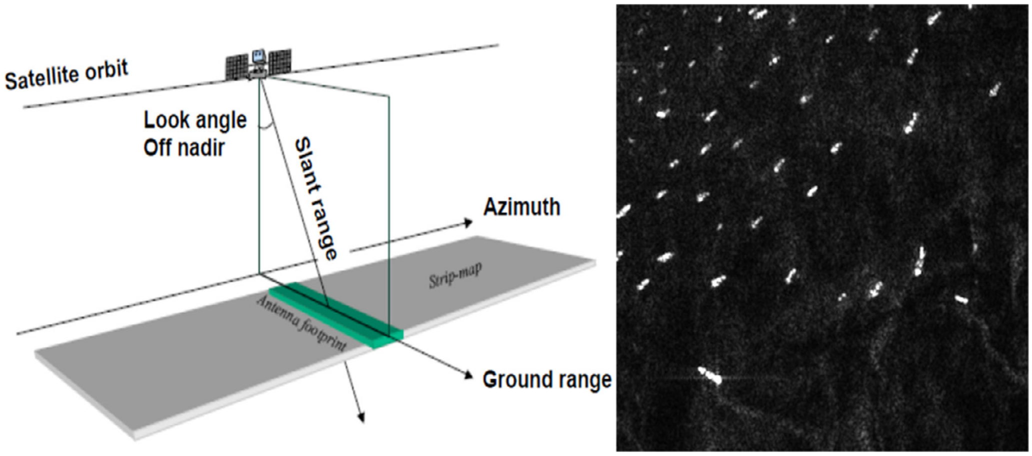

Fig. 1. Left: Side looking SAR geometry and flight path, Right: SAR image consists of the hard targets (brighter pixels due to high backscattered response) and ocean background (dark pixels due to low backscattering response) [36].

ship movements on sea and along coastlines have become the most important tasks of the coastal authorities. Most applications need the vessels to be detected and categorized as much detail as possible and afterwards the extracted information are transferred to the existing systems. Hence, fusion of information from different information systems is of great importance. For example, modern ships beyond a certain size are mostly equipped with so-called Automatic Identification Systems (AIS) and Voyage Data Recorder (VDR) systems. They identify themselves before leaving or entering a harbor and after having passed technical inspections by authorized entities [17]. The system is useful to make comparisons among different processing schemes and sensors, and to initialize the input parameters of data association and tracking algorithms, which fuses information from different sources to provide an integrated maritime surveillance picture of an area of interest [40]. The Vessel Detection System (VDS) relies on the polar-orbiting satellites carrying SAR which can be used for the detection of vessels at sea under most conditions-day and night and through clouds.

2. Geometry and system parameters for synthetic aperture radar

The detailed explanation about SAR was given by Stimson [39]. A theoretical basis for understanding the SAR images and other text context with the treatment of SAR theory was offered by Curlander and McDonough [8]. A SAR consists of an "end-to-end" system that includes conventional radar building blocks such as antenna, transmitter, receiver, and a high technology Data Collection System (DCS) providing coherent Doppler phase histories and a similarly advanced signal processor capable of making an image data out of these phase histories. "end-to-end" systems for the SAR data technology provides the details of the target image formation from the starts of the target look to the end of the target look. Furthermore, it is more suitable to generate the complete multi-look resolution imagery of the targets. A complete SAR design must be considered as an "end-to-end" set of choices or decisions linking the radar and image signal processing. Elements that must be include the moving satellite platform, transmitted signal, propagation effects, complex target interactions (including motion), received signals, data recovery and on-board or ground-based signal processing. The "end-to-end" system is as shown in Fig 2(b).

SAR is able to achieve high azimuth resolution by storing and reconstructing all the returned signals in the "synthesized aperture". By moving the radar antenna while illuminating the target and coherently processing the returned signals, a large radar aperture is synthesized and thus achieved with high azimuth resolution. SAR systems offer unique high spatial resolution regardless of the other environmental conditions, with wide area of coverage over swaths up to 500 km across. The imaging geometry of a radar system is different from the framing and scanning systems commonly employed for optical remote sensing. An imaging radar such as SAR is a side looking, that is, radar antenna beam is pointed sideways, nearly perpendicular to the flight direction of the spacecraft. SAR data can be acquired with great reliability to enable precision monitoring of Earth's surface. Most of the earth remote sensing radars operate in a part of the microwave region (1m-to-1 mm wavelength) of electromagnetic spectrum specifically L-(24 cm), C-(6 cm), S-(10 cm), and X-(3 cm) band regions respectively.

SAR system geometry is shown in Fig. 1 (left panel) and SAR imaging output of the ocean surface objects are indicated in Fig. 1 (right panel). Brighter signal signature indicates the hard targets (high backscatter response) while the dark background signal (low backscatter signal) represents the background ocean surface. The SAR systems generate large amount of data necessitating extensive process to produce images with required resolution. The process is usually performed and stored in ground stations.

The design of a SAR system is generally dependent on the application for which it is intended. Typically, specifications are provided to the design engineer by the end data user, such as resolution, incidence angle, swath width, wavelength, polarization, signal-to-noise ratio (SNR) and so on. The

Table 1
Sensor parameters of various SAR systems [44].

Parameters	SEASAT	ERS-1,2	ENVISAT-ASAR	TerraSAR-X	ALOS-PALSAR	Radarsat-2
Launch year	1978	1991,1995	2002	2005	2006	2007
Frequency (GHz)	1.27	5.30	5.30	9.65	1.27	5.40
Wavelength (cm)	23.50	5.60	5.60	3.11	23.60	5.60
Resolution (m)	25	30	30	1–18	10–157	3–100
Swath (km)	100	100	150–1000	5–100	70–350	10–500
Look angle (degrees)	23	23	20–50	20–55	10–51	20–50
Polarization	HH	VV	HH,VV	quad	quad	quad

final design is the result of an iterative procedure, balancing performance characteristics among subsystems to achieve the optimal design. No single algorithm can be defined that will optimize the design across the wide range of applications, since the priority ordering of the system performance parameters depends on the data utilization. Radar self-illuminates an area by transmitting pulses of microwave energy. These pulses of radar energy are scattered from the illuminated area and collected by the radar receiver. By precisely measuring the time difference between the transmitted pulse and receipt of the backscattered energy, radar is able to determine the distance of reflecting object (known to be slant-range). Various SAR systems and satellite sensor parameters are provided in Table 1.

2.1. SAR signal processing techniques

Signal processing can be any technique that changes the characteristics of the signals such as amplitude, phase, frequency, and polarization. In a SAR signal processor, there are specific operations required to convert the raw data sets to interpretable image. Raw SAR data is not an image since the point targets are spread out in both range and azimuth directions. Modern SAR systems use the digital signal processing technique to improve the azimuth and range resolutions. The image generation is always in a raw form. Signal processing techniques can be broken into two phases: range and azimuth compression [12]. The azimuth compression is because each echo reflected from a single point target has a different phase shift. The azimuth compression operation focuses the echo signal in such a way that a zero phase shift remains and integrates the focus echo. As a result, the azimuth resolution is improved. A number of algorithms have been developed to effectively process the SAR data from its raw signal into the well-focused images. The most common SAR processing algorithm is the range Doppler algorithm, which accurately and effectively accommodates the range varying parameters such as Doppler Centroid, azimuth frequency modulation rate, and range cell migration [31].

2.2. Synthetic aperture formation and Doppler data processing

SAR achieves the high spatial resolution in the azimuth direction with help of the synthesized aperture formation. A synthetic aperture, or virtual antenna, consists of a long array of successive and coherent radar signals that are transmitted and received by a physically short (real) antenna as it moves along a predetermined flight or orbital path. Fig. 2 shows the basic formation of SAR length, the aperture length is the distance between the point from where the SAR start looking to view the target and the point at which it stops to view the target. Ground covered by the SAR platform under the illumination of radar beams is known as a swath. SAR signals are stored in the form of inphase (a) & quadrature (b) components, and these signals are subjected to range and azimuth components to obtain an image. SAR transmits the chirp signal and the equation of chirp signal can be expressed as,

$$s(t) = A.\exp\left(i.2\pi\left(f_c.t + \frac{kt^2}{2}\right)\right) \tag{1.1}$$

where A, f_c, k, and t are the amplitude, signal carrier frequency, chirp slope, and time duration of pulses respectively.

Due to relative motion between the target and spacecraft (or aircraft), the return signals from the target are frequency shifted (known as Doppler shift). The return signal frequency increases when the spacecraft approaches the target, and it decreases when spacecraft is going far away from the target. The Doppler frequency information is used to form a large aperture. The Doppler frequency shift is proportional to the rate, at which the range between satellite and the target changes and the governing equation can be defined as,

$$f_D = -\frac{2\dot{R}}{\lambda_r} = -\frac{2}{c}\dot{R}f_c \tag{1.2}$$

Where f_D, c, λ_r, f_c, and $\dot{R}$ terms indicates Doppler frequency shift, speed of electromagnetic waves, radar wavelength, radar carrier frequency, and slant-range rate respectively. Along track geometry of SAR system is shown in Fig. 3, where V_s is the spacecraft velocity, H is the height of the spacecraft above the earth surface, R is the range between the spacecraft and target, x is the along-track position of the target, R_g is the across-track location of the target, θ_a is the along-track angular position of the target, R_b is the broad-side range of the target and s is slow (integration) time.

The equation has been proposed by Curlander and McDonough [8]. Using Trapezoid properties (from Fig. 3), it can be written as,

$$R^2 = (x - sV_s)^2 + R_g^2 + H^2 \tag{1.3}$$

From the above equation, the range rate can be calculated by an assumption of reference frame moving with spacecraft

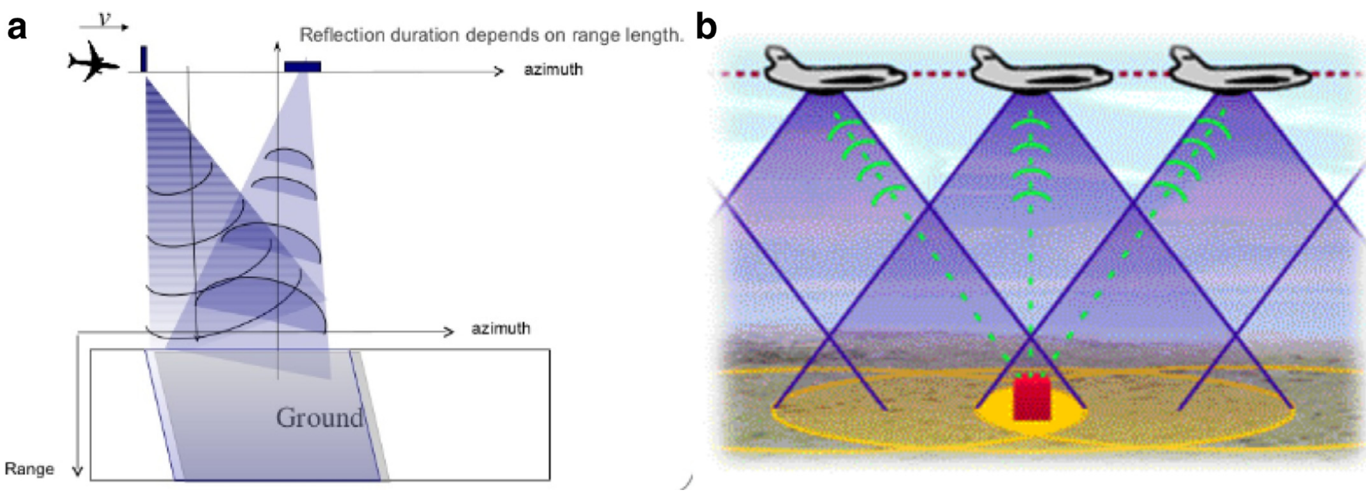

Fig. 2. Synthetic aperture lengths (a), concept of array of real antenna positions forming a synthetic aperture (b) focused target image formation [36].

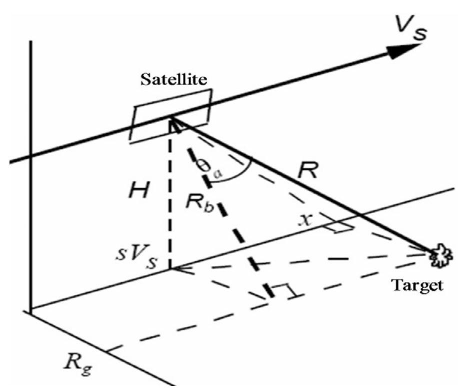

Fig. 3. Along track geometry of a SAR system.

($s = 0$) and differentiating R (*i.e.*, Eq. (1.3)) with respect to s as follows,

$$\dot{R} = -\frac{x}{R}V_s \tag{1.4}$$

Substituting the value from Eq. (1.4) in Eq. (1.2), we obtain the Doppler frequency as follows:

$$f_D = \frac{2V_s x}{\lambda_r R} = \frac{2\,V_s \sin(\theta_a)}{\lambda_r} \tag{1.5}$$

2.2.1. Doppler frequency rate (f_R)

The rate at which the frequency of the return from a target changes as the target passes through the radar footprint is called the Doppler frequency rate, which can be expressed as,

$$f_R = \frac{2\ddot{R}}{\lambda_r} \tag{1.6}$$

Taking differentiation of Eq. (1.3) twice, we get,

$$\ddot{R} = \left(\frac{V_s x - V_s{}^2 s}{R^2}\right)\dot{R} + \frac{V_s^2}{R} \tag{1.7}$$

The first term is very less than the second term (from Eq. (1.7)), we get,

$$\ddot{R} = \frac{V_s{}^2}{R} \tag{1.8}$$

2.2.2. Doppler centroid frequency (f_{DC})

The frequency of the return from the target when it is located in the center of the radar beam is the Doppler Centroid Frequency (f_{DC}), which can be expressed by the following relation,

$$f_{DC} = -\frac{2\dot{R}_c}{\lambda_r} \tag{1.9}$$

The various equations were derived in order to understand the physical phenomena of SAR signals under the relative motion between targets and satellite with the concept of Doppler's effect. A full, detailed description of SAR theory is beyond the scope of this work but some basics are needed in order to understand the ship detection problem in addition with retrieval of wave parameters using SAR. The important properties, which are achieved by the SAR in order to form an image, can be described below.

2.2.3. Azimuth resolution

The direction orthogonal to radar beam is called the azimuth direction or cross range direction. It is defined as the resolution along with the direction of flight. The azimuth resolution depends on the antenna beam width (β), and ground range resolution (R_g). The well-known definition as shown below is described by Beckmann and Spizzichino [5] among others, and began with the azimuth resolution for SAR. The resolution is independent of the range and the radar wavelength, and improves with smaller aperture.

$$r_{ap} = \frac{d_a}{2} \tag{1.10}$$

where r_{ap} and d_a are the azimuth resolution and antenna aperture length respectively.

2.2.4. Range resolution

Range resolution of radar is the ability to determine the minimum distance between two objects, if the objects are separated from each other, each will be located in different resolution cell, if not then the radar reflection will be the complex combination of reflected energy from the two objects. For SAR sensors, the range resolution (r_r) can be expressed as,

$$r_r = \frac{ct}{2\sin\theta} \tag{1.11}$$

where c is the speed of electromagnetic waves, θ is the incident angle between radar beams and normal to Earth's surface and t is the pulse duration. Correct and accurate pulse duration is needed to achieve a reasonable and sufficient echo signal-to-noise ratio (SNR). In practice, many factors can affect image quality by causing the signal amplitude or phase modulation.

3. Application of SAR

SAR images have become an integral part in numerous scientific disciplines. The potentials of SAR in a diverse range of applications are listed below [32].

(a) Sea and ice monitoring.
(b) Oil pollution and environment monitoring.
(c) Vessel monitoring and surveillance.
(d) Snow and sea ice monitoring.
(e) Classification of earth terrain.
(f) Wave spectra and significant wave height measurements etc.
(g) Marine laver cultivation monitoring.

SAR Processing Products

(a) Quick Look or Browse Image Product.
(b) Single Look Complex Image.
(c) Multilook Intensity Image.
(d) Geocoded Ellipsoid Corrected Product.
(e) Terrain Corrected Product.

Advantages of SAR

(a) All weather capability (small sensitivity of clouds, light rain).
(b) Day and night operation (independence of sun illumination).
(c) No effects of atmospheric constituents (multitemporal analysis).
(d) Sensitivity to dielectric properties (water content, biomass, ice).
(e) Sensitivity to surface roughness (ocean wind speed).
(f) Accurate measurements of distance (interferometry).
(g) Sensitivity to manmade objects.
(h) Sensitivity to target structure (use of polarimetry).
(i) Subsurface penetration.

Disadvantages of SAR

(a) Complex interactions (difficulty in understanding, complex processing).
(b) Speckle effects (difficulty in visual interpretation).
(c) Topographic effects.
(d) Effect of surface roughness.

4. SAR image interpretation

The general rules for SAR Image Interpretation are as follows:

(a) Regions of calm water and other smooth surfaces appear black, because the incident radar reflects away from the spacecraft.
(b) Surface variations near the size of the radar's wavelength cause strong backscattering.
(c) A rough surface backscatters more strongly.
(d) Wind-roughened water can backscatter strongly when the resulting waves are close in size to the incident radar's wavelength.
(e) Hills and other large-scale surface variations tend to appear bright on the side that faces the sensor and dim on the side that faces away from the sensor.
(f) Due to the reflectivity and angular structure of buildings, bridges, and other man-made objects, these targets tend to behave as corner reflectors and show up as bright spots in a SAR image.

5. SAR imaging scenario for the ships in ocean

A SAR instrument transmits pulses of electromagnetic radiation and then measures the amplitude and phase of reflected radiation from the ocean, land, or man-made objects. Vessels are typically constructed from large flat metal sheets. Ships which moves offshore tend to be larger and made of metals with high dielectric constant (*i.e*., from materials that are good electrical conductors), whereas coastal boats are smaller and made of wood or fiberglass (*i.e*., non-conducting materials). Corner reflectors have the property of returning radiation back to the source, or parallel to the incoming direction [1,2,15]. Ships often contain superstructure or deck configurations that act as direct reflectors or corner reflectors. Ships are good microwave reflectors, or hard targets, in a sense acting as radar corner reflectors. They return a large portion of the incident energy back to the SAR sensor and may appear in the SAR imagery as relatively bright points or elongated bright blobs [20,21,43].

The direct radar return from a ship is the most common ship signature in SAR imagery. Also, a ship traveling perpendicular to the radar beam (*i.e*., traveling in the same direction as of the satellite) presents as a larger target and has the possibility of a greater double reflection return [34,45].

Depending on the SAR resolution, the SAR image signature of a ship may be a single pixel with significantly greater normalized radar cross section (*i.e.*, large backscatter and therefore brighter) than surrounding pixels or, at higher resolution (*e.g.*, 30 m or better), a superstructure may become distinguishable [42]. As long as the ship has good radar backscatter characteristics, even ships smaller than the SAR pixel resolution can easily be detected under a wide range of wind and wave conditions. Automated ship detection algorithms generally look for a statistically significant contrast between the ship and the local ocean background [6,16,25]. A single detection threshold cannot be used for the whole image since the background backscatter changes substantially with SAR angle of incidence, wind speed and sea state. Due to this strong hard target behavior, the location of fishing fleets can be easily determined using SAR imagery [35]. There is some limitation for the detection of ships in an image and can be grouped into following five categories [46].

- Metrological conditions.
- Radar characteristics.
- Image resolution.
- Imaging mechanism.
- Ship characteristics.
- Image quality.

The most important ones are image resolution, speckle noise and image distortions due to the dynamic environment, which add uncertainty in the final report. SAR image processing errors and the inherent speckle noise in SAR imagery can interfere with ship detection algorithms. In addition, another interesting SAR image phenomenon related to ship detection is the displacement in the SAR image of a rapidly moving ship under certain incidence angle. A moving ship with a substantial velocity component in the radar range direction (*i.e.*, a ship traveling relatively perpendicular to the direction of motion of the SAR satellite) will be displaced (in the SAR image) off its turbulent wake or off the apex of its V-wake by a distance proportional to this velocity component [22]. This is a SAR imaging artifact resulting from placing the ship in a different image azimuth location (*i.e.*, in the image dimension parallel to the satellite motion) than the ocean pixels surrounding the ship, as a result of an extra Doppler shift from the ship's motion relative to the sea surface. If a ship is moving away from the SAR platform, its image will be displaced in the negative azimuth direction; motion towards the SAR platform will result in positive azimuth displacement [27].

Ship detection in SAR imagery has become an important and routine application in most of the countries. One of the main problems in ship detection is the presence of sea clutter inherent to coherent imagery. A traditional approach to differentiate a target imbedded in noise is to utilize the statistical property of the clutter with some success. The ship detection algorithms such as constant false alarm rate (CFAR), alpha-stable algorithms, wavelet transforms were implemented to the date in order to carry out the research on ship detection, but these algorithms are limited due to the presence of sea clutters and speckle noise in SAR images. Integration of SAR and AIS is the challenging tasks now days due to the different sensor properties and channel bands. As far ship detection is concerned, various articles have been reviewed and it has been found that the previously developed models depend on the detection of ships in the image itself instead of integrating the image information with other sensor data such as AIS and ground-based radars and navigational systems. A little work has been carried out to design an operational ship monitoring system with the use of SAR and AIS.

This model relies on comparing the image intensities between the ships signatures and oceanic background, but it also depends the image properties [33,37]. Vachon et al. developed a model for ship detection using the various beam modes for C-band SAR, and this model was updated by the Canadian Center of Remote Sensing (CCRS) and implemented in the Ocean Monitoring Workstation (OMW). This model was used to estimate the minimum ship's length based on the comparison of radar cross section (RCS) of ships as well as the ocean. Successful SAR detection of ships depends, nevertheless, on the size and type of vessel, prevailing wind speed conditions, SAR resolution used and viewing angle [44,45]. Lin and Khoo presented a general concept for the ship speed estimation using an azimuth shift concept with known course from the range direction. The distributions such as Gamma or K- distribution have also been suggested by Jiang et al. but they carry the same limitations as the Gaussian distribution. In general, as sea clutter in SAR images always shows spiky or heavy-tailed characteristics, these distributions often fail to describe heavy-tailed sea clutter in many actual applications. Margarit suggested an approach merging of satellite remote sensing and environmental stress to ensure marine safety for the navigational waters off the radar range [33].

Various ship detection algorithms and reviews can be found in Arnesen and Olsen . CFAR algorithm is widely used for computing the adaptive threshold. To use the CFAR algorithm, one must first determine an appropriate probability density function (PDF) that can adequately describe the statistical characteristics of background [13,14]. For multilook SAR images, a commonly used PDF is the Gaussian distribution [4]. Crisp explored the most important ship detection software "Analysis Detection Support System (ADSS)" based on the adaptive threshold algorithm. This software was developed at the Department of Science and Technology Organization (DSTO), Australia for the automatic detection of targets in SAR imagery [11]. For a multilook SAR intensity image, when the number of looks is over 30, it is suitable to assume the Gaussian PDF of clutter in the multilook image. Therefore, The Gaussian distribution is only valid when a large number of radar looks are averaged. However, detection ability of ocean features decreases with high sea states due to the higher level of clutter, thus an alternative method is required to identify ships from the wake lines.

Many researchers from the various organizations and research institutions have been making efforts to explore an appropriate method to integrate SAR (large coverage instrument) with AIS (short coverage instrument) in order to design and operate a real time monitoring system for detecting and identifying the ships in coastal and open sea. Since the data fusion of SAR and AIS are the ongoing research in various organizations throughout the world, very little information are available in literature on this subject. The continuous monitoring service will significantly benefit from such independent monitoring capabilities [24,41]. The first operational services were developed in the early nineties and rely on the usage of active on-board transponders. There, GPS-based receivers provide the real-time ship status to monitoring centers via satellite communications. Such systems have proven to be very accurate for supporting decision making but an intrinsic limitation, which is related to the transponder itself. Vachon et al. used the number of RADARSAT-2 datasets for the ship detection and recognition at the different acquisition times and which was validated with the consequent Live AIS signal reports to design a real-time monitoring system [45].

The most general concepts for discrimination of the detected targets, where those associated with SAR-AIS contacts are defined as ships, and non-associated targets are declared as false targets [18,19]. An operational ship monitoring system based on SAR processing with the use of AIS data sets carried to integrate the SAR and AIS datasets [9,11]. They presented an operational ship displaying system but there was no evidence for the matching of both datasets. The Kongsberg Maritime Group, Norway, where an automatic real time system for coastal monitoring was developed, described positioning concept and the results of the ships detection near the coasts of Norway were discussed, although the information concerned with SAR and AIS derived vessels within the confined image boundary did not contain any specific evidence of their matching criterion [26–28].

The previous studies on ship detection by SARs are, of course, very useful, but many of which are often limited to ships in open sea rather than those in coastal regions. Ship detection and identification by SAR in coastal waters and ports have several problems to overcome, since many ships with varying sizes and types with and without AIS transponders exist in these highly complex and busy ship traffic regions [4,29].

Arnaud's scheme is therefore to: extract two non-overlapping Doppler bands from the raw SAR data; form the SLC images for each look; and then form an interferogram and its "phase coherence image". Pixels with high "phase correlation" are expected to be ship pixels. Arnaud detects them by applying a simple threshold to the phase coherence image. Arnaud has applied this method to ERS-1 SAR data with promising results. However, the tests were not extensive and the imagery was not ground-truthed so although feasible, the practical utility of the method has not been demonstrated. Arnaud notes that the method can be fine-tuned and some improvements may result from considering the following: the width of the Doppler sub bands used; the spectral separation of the Doppler sub bands used; the method of computation of the coherence image (and especially the window size used). On the first two points, Arnaud comments that both the separation and sub bandwidths need to be increased in calm seas to enhance the decorrelation of the sea whereas in agitated seas they need to be reduced to avoid the decorrelation of the ship [48]. In general, the SAR geocoded products are used for applying and analyzing the processed image for the target detection with the positional information on the earth's coordinate.

6. Automatic identification system (AIS)

AIS (Automatic Identification System) as shown in Fig. 4 is one of the first open standard data broadcast communication system onboard onto the ships, operating in the VHF maritime band and adopted within the global maritime environment. A cooperative, large scale systematic open seas ship identification function can be provided using space-borne sensing and AIS signal in a transparent way for ships (which gives it a strong interest). Studies and experiments are in progress for the reception of AIS signals from space by small low-Earth orbit constellations, with an objective of efficient coverage around 2014. However, though it may provide interesting results, the recent deployment of the space-based AIS systems has faced issues linked with discrimination from space of ships AIS signals coming from dense maritime areas. This specific issue dramatically degrades the quality of service expected from such space-borne extended AIS systems [38].

Today, it is possible to obtain AIS reports from the AIS chain of receivers located near to the coast. This makes it possible to compare satellite SAR images taken over the coastal regions with AIS data, and subsequently build up knowledge about the SAR detection capability for various ships and SAR modes. The "true" data is displayed on the side of the PPI above the radar target data selected. It is not clear whether, if a sea stabilized display is selected on the radar, the AIS data will stay as true ground datum display or whether it is further processed. If the AIS data is requested of a target then the course and speed given are directly related to the mode in which the radar vectors are displayed, *i.e*. either relative or true data. This of course differs from standard AIS data which is true. The AIS data is being processed by the radar and is not necessarily that which is transmitted by the target vessel. The AIS is capable of sending ship information, such as identification, position, course, speed, sizes, draught, and ship type to other ships and to the shore. The main purpose of AIS is

- To identify vessels.
- To assist target tracking.
- To simplify information exchange.
- To provide additional information to assist collision avoidance.

It is capable of handling over 2000 time slots/minute/channel and updates as often as every two seconds. The AIS uses Self-organizing Time Division Multiple Access (SOTDMA) technology to meet this high broadcast rate and ensures reliable operation. Timing information is derived from

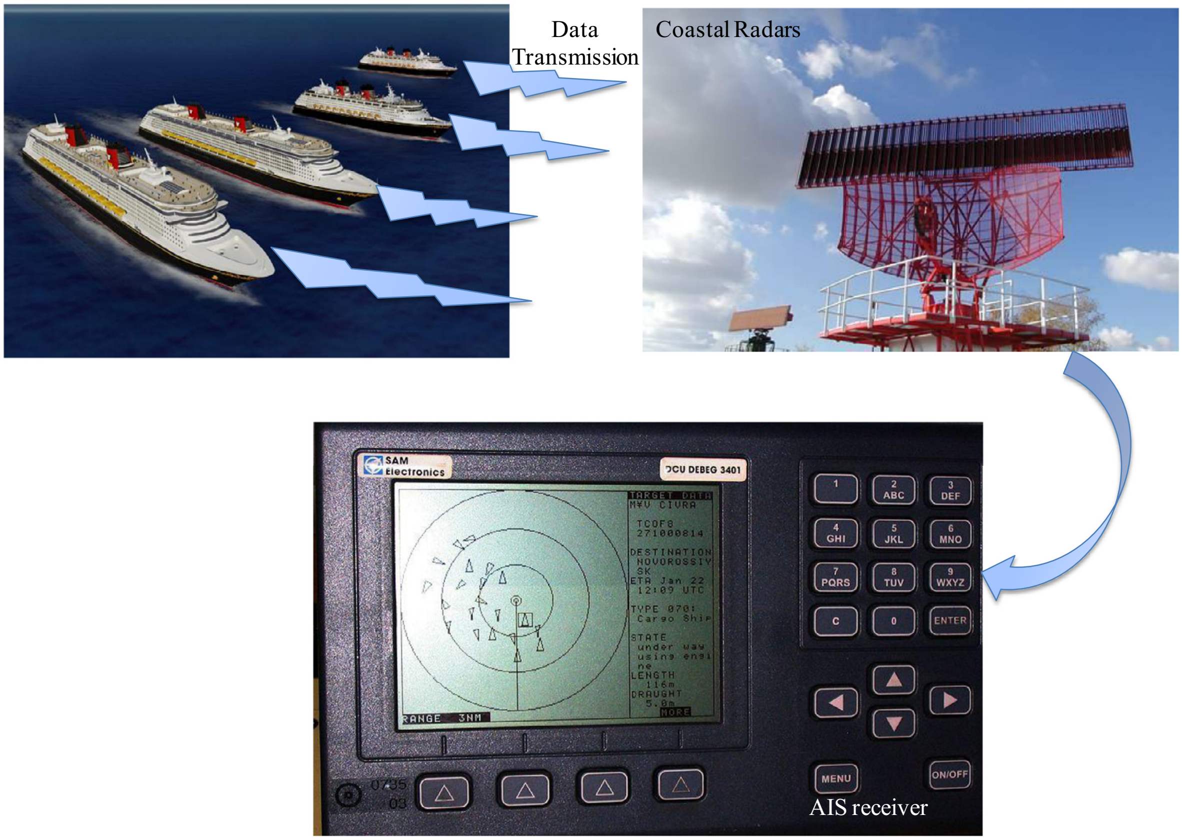

Fig. 4. AIS data transmission system [23,30,19].

an integral global navigation satellite system (*e.g.*, GPS) receiver and the detailed information could be found at AIS manual. The effectiveness of AIS may be significantly increased by integrating it into other devices such as Electronic Chart Display (ECS)/Automatic Radar Plotting Aid (ARPA). The AIS can use both 25 and 12.5 kHz simplex channel bandwidths. When operating with either of these bandwidths, the resulting capacity is 2250slots/min at a transmission rate of 9600 bits/s. The complete data transmission system for an AIS is shown in Fig. 1.4. Each ship in ocean transmits their respective identity information to the coastal-based radars. The data obtained by these radars are then further decoded for interpretation and displayed on the AIS receiver system (IMO user manual). The IMO defines the "Voyage Data Recorder" as a complete system, including any items required to interface with the sources of input signals, their processing and encoding, the final recording medium, the playback equipment, the power supply and dedicated reserve power source. Information is stored in a secure and retrievable form, relating to the position, movement, physical status, command and control of a ship over the period and following an incident. This information is used during any subsequent safety investigation to identify the cause(s) of the incident. Aside from its usage in accident investigation, it can also be used for preventive maintenance, performance efficiency monitoring, heavy weather damage analysis, accident avoidance and training purposes to improve safety and reduce running costs [23].

6.1. AIS datasets

There are different message types, including the ship's data, required by the International Maritime Organization (IMO) performance standards as follows [23,26].

(a) Static and voyage related data (name and call sign, MMSI (maritime mobile service identification), size, type, draught, route plan etc.).
(b) Dynamic information (ships position, time of data transmission, course over ground (COG), speed over ground (SOG), heading, rate of turn (ROT), pitching, yawing etc.). The report rate for the dynamic information for various ships navigation status is listed in Table 2.

6.2. Benefits and advantages of AIS

(a) Improved vessel tracking.
(b) Wider geographical coverage.
(c) Greater positional accuracy.
(d) Absence of "radar shadow" areas.
(e) Real time maneuvering data.
(f) Provision of more precise navigational advice.
(g) Improved search and rescue management.

Table 2
Report rate of dynamic information [7].

Ship's maneuvering condition	Reporting interval
Ship at anchor (speed < 3 knots)	3 min
Ship at anchor (speed > 3 knot)	10 s
Ship 0∼14 knots	10 s
Ship 0∼14 knots and changing course	3.33 s
Ship 14∼23 knots	6 s
Ship 14∼23 knots and changing course	2 s
Ship > 23knots	2 s
Ship > 23 knots and changing course	2 s

(h) Electronics transfer of safety messages.
(i) Automatic indication of voyage related information.

In particular, a large amount of AIS signals is transmitted from ships, and signals from different ships sometimes overlap, some of which become missing, causing difficulty in sorting the AIS signals corresponding to the correct ships in the SAR image. Further, matching of the AIS information with the corresponding ship in the SAR image also becomes difficult. This work presents the first and new step towards the matching of SAR and AIS near coastal regions by means of the dead-reckoning (DR) position estimation from AIS signals, and the nearest neighbor search procedure from the estimated DR followed by size and speed matching between the SAR and AIS.

7. Conclusions

In this article, we explained the basic theory of SAR, background of the research work with the various applications of SAR and AIS in ocean science and technology. SAR imaging concepts of ships and oceans have been explained and basic information of the integrated system design for vessel detection using SAR and AIS has been presented. These results may be considered as a preliminary stage for the development of the integrated system for ships recognition over oceanic region. It is very novel to monitor ships in coastal waters or the open sea with correction of position shifts and they are presented on the user graphical screen for better understanding of the results. This research paper work will contribute to the design of an operational system using a real-time satellite-based monitoring system (*e.g.,* SAR), and ground based monitoring (*e.g.,* AIS and radar) for ship monitoring in coastal regions with very dense traffic levels. Currently, a study is underway to develop an operational automatic system for different SAR sensors at different acquisition modes and polarizations with different acquisition geometry and different acquisition time. Only ship-borne AIS datasets have been considered for the integration. In future work, we will try to get Satellite AIS datasets for validation purposes.

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