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A Survey on Detection and Imaging Techniques for UAVs using RADAR

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Abstract: **In this work, we discuss about different types of radars. We also discuss the image processing part of the data received through these different types of radars. We will get an overall view of how radar function, what are its types, and imaging techniques. We look at the scattering mechanism of electro-magnetic waves which takes place after hitting the target. We also look at the band distribution on different waves. We derive some necessary equation for knowing the target better. We see some effective imaging techniques which are commonly used for both civilian and military purposes.**

Keywords: **Classification, radar, continuous wave (CW), range, doppler effect, doppler frequency, SAR, ISAR, UAV.**

I. INTRODUCTION

The radar uses electro-magnetic waves to detect the targets. There are essentially three types of radars. Nowadays radars are used for civilian as well as military purposes. In military, they are used to detect targets within the specified range. With the continuous invention of now techniques and increasing accuracy and efficiency of the existing techniques, it is now very important that we understand how radar and its imaging techniques work and how they can be improved. Also, imaging techniques are being developed to get more accurate and suitable images of these radar systems. We also must take note of which technique is most suitable for the required use case [1-5]. The uses of radar in the modern world are incredibly varied, and include guided missile target locating systems, self-driving cars, ground-penetrating radar, air and terrestrial traffic control, radar astronomy, air defense systems, anti-missile systems, marine radars to locate landmarks and other ships, aircraft anti-collision systems, ocean surveillance systems, outer space surveillance and rendezvous systems, meteorological precipitation monitoring, altimetry and flight c13ontrol systems, and Digital signal processing, machine learning, and high-tech radar systems are all used to extract valuable data from extremely high noise levels.

II. RADAR SYSTEM

Radars can be categorized as being either ship-based, airborne, spaceborne, or ground-based. Depending up on the specific characteristics of radar, they can also be divided into a variety of categories, such as the frequency band, specific antenna type, and waveform employed. Continuous Wave (CW) radars are defined as systems that use continuous waveforms, whether modulated or not [6-10]. Radars can also be categorized according to how they are used, including for weather, tracking, warning, and a variety of other purposes [11-13]. The band distribution table is shown in table 1.

III. SCATTERING MECHANISM

Once the electro-magnetic waves are transmitted by the radar, they hit the target which is in the range of that radar. After hitting the target, the electro-magnetic waves get scattered after which they are caught be the receiver in the radar system [14-16]. There are different types of scattering patterns after the waves hit the target such as double diffraction at sharp corners, diffraction from circular object, diffraction on edges, multiple reflections, specular (which is precise reflection that satisfy Snell's Law) and surface waves(the surface of the body acts as a transmission line).

IV. RADAR DETECTION AND RANGING

(i) Quasi-Monostatic: - The radar type in which even though transmit antenna and receiver antenna are separated to some extent, they still seem to be at the same location as viewed from the target.

(ii) Bistatic: - The radar in which the transmitting antenna and receiving antenna are at various locations as viewed from the target. For example, ground transmitter (Tx) and airborne receiver (Rx).

(iii) Monostatic: - The radar in which the Tx (transmitter) and Rx (receiver) seems to be same as viewed from the target. For example, the same antenna is used to transmit and receive [17-21].

Table.1 BAND DESIGNATION TABLE

	Band Designation	Frequency Range
1	HF	3-30 MHz
2	VHF	30-300 MHz
3	UHF	300-3000 MHz
4	L	1-2 GHz
5	S	2-4 GHz
6	C	4-8 GHz
7	X	8-12 GHz
8	Ku	12-18 GHz
9	K	18-27 GHz
10.	Ka	27-40 GHz
11.	V	40-75 GHz
12.	W	75-110 GHz
13.	mm	110-300 GHz

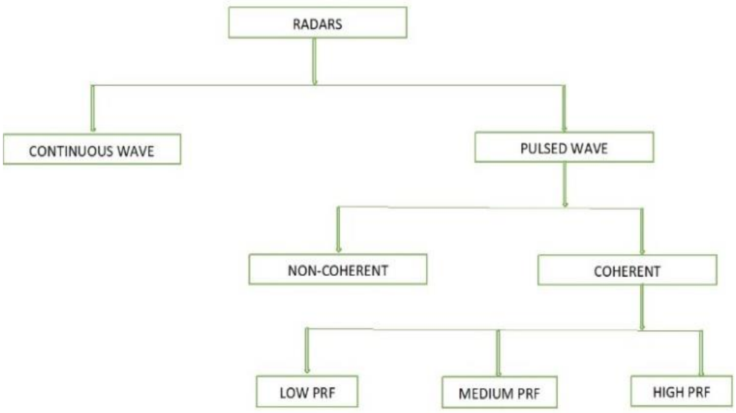

Fig. 1 FLOWCHART

For example, on the same plane, there is a broadcast and receive antenna. The radar receiver's lowest detectable received power is referred to as the minimum detectable signal (MDS) denoted by δ min [22-25]. Classification of waveform is given in fig 1.

V. RADAR FUNCTIONS

Radar functions can be categorized into two categories: normal functions and signature analysis of inverse scattering. In Normal Functions[26-27], we can find

(i) Range, which is determined by pulse delay;

(ii) Velocity, which is determined by Doppler frequency shift; and

(iii)Angular direction, which may be determined by straightforward antenna pointing.

We can determine the following in Signature Analysis and Inverse Scattering:

(i)Target size, which is determined by measuring the magnitude of returning waves;

(ii)Target shape and components, which are determined by returning waves as a function of direction;

(iii)Moving parts, which are determined by modulating the returning waves; and

(iv) Material composition [28-30].

VI. DOPPLER EFFECT

A Doppler shift occurs only when radial component is present for the relative velocity vector. The bandwidth of noise of the doppler filters is small compared to that of the total bandwidth of the radar, which improves the SNR [31-34]. In radar system, if the target is not stationary then change in frequency of signal takes place that the radar received. This effect is called as Doppler Effect [27-30]. According to Doppler Effect change in frequency occurs as: -

(1) Target will increase the frequency of the signal being received if it travels in the direction of the radar.

(2) When a target travels away from a radar, the frequency of the signal that is received will also decrease [35-38].

A. DERIVATION OF DOPPLER FREQUENCY

Let us assume R is the range of the target and λ the wavelength. The energy travel from the radar antenna to the target and from target to the radar then the total wavelength is given by 2R/λ and there is 2π radian is the phase change [39-41].

The unit for R and the λ is considered same.

As the energy travel two-way so than the phase change(ϕ) in total is,

$$\phi = 2\pi\left({}^{2R}/_{\lambda}\right) \text{ or } \phi = {}^{4\pi R}/_{\lambda} \text{ rad}$$

The R will change continuously as the target is in motion so the phase will also change accordingly. A change in phase with respect to the time may be called as angular frequency ω may be given by,

$$\omega = 2\pi f_d = d\phi/dt \quad (1)$$

$$=\left({}^{4\pi}/_{\lambda}\right).\left({}^{dR}/_{dt}\right) \quad (2)$$

therefore,

$$ {}^{4\pi V_r}/_{\lambda} \quad (3)$$

where,

fd=Doppler frequency shift

V_r=radial velocity or the rate of change in range with time

If the angle in between the radar and the target antenna is θ, then the radial velocity may be written as vcosθ,

from the eq. (1) and eq. (3) we can write the modified equation as below;

$$2\pi fd = {}^{4\pi V_r}/_{\lambda}$$

$$f_d = {}^{2V_r}/_{\lambda} \quad (4)$$

$$f_d = {}^{2fV_r}/_{c} \quad (5)$$

Eq. (4) and (5) are the final equation of the Doppler Frequency. where,

f=transmitted frequency,

c=velocity of EM waves=3×10^8m/sec,

f_d=Doppler Frequency Shift

VII. IMAGING TECHNIQUES

Radar is generally utilized in imaging, which creates two-dimensional images, which are usually landscapes[42-45]. To create a photograph of a region on the ground and light it with radio waves, imaging radar emits light. It registers its photographs using a computer storage device and an antenna. Radar images show the energy that was reflected alone in the direction of the radar antenna[46]. The radar turns along a flight path, and its footprint—the area it illuminates—moves across the surface, building an image as it moves[47].

There are many dots that make up digital radar images. Radar backscatter is represented by each pixel in the radar picture; brighter areas correspond to high backscatter, while darker areas correspond to low backscatter[48-51]. Radar is typically used for detection of direction and reflected signal delay by transmitting a radio wave signal and subsequently displaying the spot and velocity of highly reflective object (such as ships and aircrafts). Contrarily, imaging radar tries to produce an image of one object also by calculating the reflected signal strength to measure the scattering degree. A two-dimensional plane is used to map the registered electromagnetic dispersion, and spots with higher reflectivity are often given brighter colors to produce an image[52-56].

Many methods have been developed to do this. They typically make use of the Doppler effect, which is brought on by rotation of the body or another motion, along with the fluctuating perception the motion of the object (usually a plane) is caused by the interaction between the backscatter and the body, which is detected by the radar of the object[57-59]. Radar imaging is becoming more precise thanks to recent method changes. Imaging radar is being used to classify targets for military systems as well as map the planets, asteroids, and other celestial bodies, including the Earth[60-63].

A. SYNTHETIC APERTURE RADAR (SAR)

Synthetic aperture radar (SAR), a type of radar, is used to create two-dimensional reconstructions of things or three-dimensional images of them, including landscapes. SAR moves the antenna of radar around a target region to give better particular resolution than traditional stationary beam-scattering radars[64-65]. The origins of SAR can be found in an advanced type of side looking airborne radar, which is often kept on a moving platform, such as an airplane or spacecraft (SLAR). The distance travelled by the SAR device over a target during the time when the target scene is lighted (the antenna size) determines the large synthetic antenna aperture[66-69].

Generally speaking, it does not matter if the larger the aperture, whether it is a physical aperture (a massive antenna) or a synthetic aperture (a moving antenna), the better the picture resolution; this enables SAR to create high-resolution images with relatively tiny physical antennas[70]. SAR has characteristic of establishing massive synthetic apertures for far away objects because given a fixed antenna size and orientation, farther away objects remain lighted longer[71-73]. This produces a constant spatial resolution all over a variety of observing distances.

When trying to extract information from SAR images, we need to differentiate two types of image property. The more important is where properties of the UAV yield effect in the image; measurements or examination of the image then can provide the information about the UAV[74-77]. The second is generated totally by use of the system's signal processing. Sample SAR image is shown in fig 2.

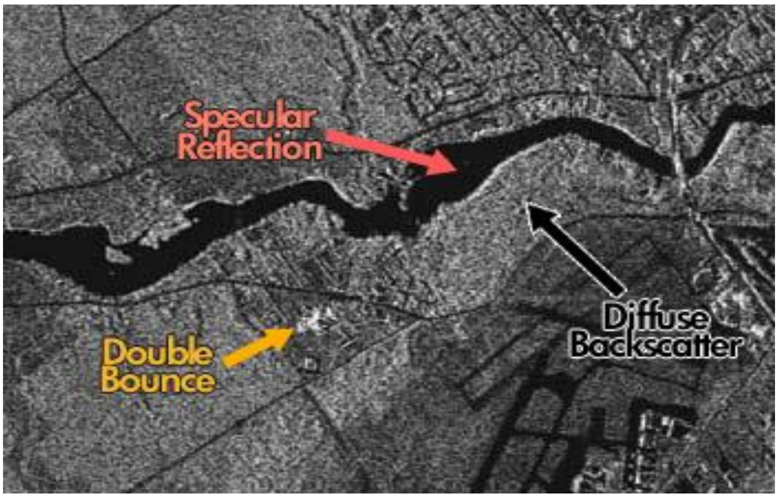

Fig. 2 SAR IMAGE

B. INVERSE SYNTHETIC APERTURE RADAR (ISAR)

Inverse Synthetic Aperture Radar (ISAR) is a type of SAR that can be used operationally to image targets such as UAVs. The technique also has application to instrumentation radar for evaluating radar cross section of targets and target models[78-80]. ISAR can be explained in terms of SAR by referring to the spotlight form. After correcting for deviation from straight line motion, a spotlight SAR can be thought of as if radar were flying an angular segment ψ of a circle around the target area.

ISAR images of the target region are helpful in finding scattering patches on that specific target. By rotating the target and examining the Doppler histories of the scattering centers, ISAR images are usually produced.

If the target turns through a 'small' angle in azimuth at a consistent rate, scatterers are going to approach or retreat from the radar at a rate determined only by the cross-range position which is the distance perpendicular to the radar line of sight with the origin at the target axis of rotation[81-83]. This turning will create Doppler frequencies which are dependent on cross range, that may be spatially sorted using a Fourier transform. Because of the coherence addition of receiver outputs for various target / antenna geometries, this procedure is the same as (but the opposite of) creating a huge synthetic-aperture phased-array antenna[84]. The 2-dimensional Fourier transform of the signal received as a function of frequency and target aspect angle creates the ISAR picture for small angles. If a scatterer is spun across enormous angles, the Doppler frequency history becomes non-linear and moves along a sine wave trajectory.

Due to the fact that the smeared Doppler frequency history cannot be directly processed by a Fourier transform, a loss is detected in cross range resolution. The requirement that the aperture phase error across the synthetic aperture exceeds a certain value determines the maximum rotation angle that an unmodified Fourier transform can handle, must not deviate by more than a certain (arbitrary) angle, such as 45 degrees[85]. When the synthetic aperture to the target range is smaller than what the $2D^2/\lambda$ limit specifies, where D is the necessary lateral extension of the target, this happens[86-87]. The synthetic aperture is now located inside the target nearfield region and demands concentration. A phase adjustment is made to the artificial aperture, the focusing can be accomplished. Sample ISAR images of a car is shown in fig 3.

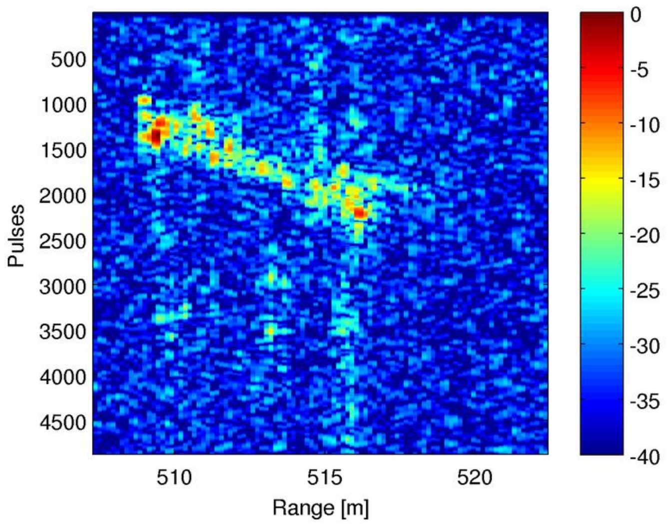

Fig. 3 ISAR IMAGE OF A CAR

C. ACOUSTIC SIGNALS

Acoustic signals are generated by a time varying pressure field is a material medium and this is brought about by a target. The vibration of the target produces compression and rarefaction in a fluid medium. If the frequencies are under 20 Hz, the waves are known as Infrasonic Waves. If frequencies are between 20-20,000 Hz, then they are known as Sonic Waves. The frequencies above 20,000 Hz become inaudible and are called Ultrasonic Waves. Sensing of acoustic signals helps us in sound ranging for locating the target [88]. The strength of interaction of acoustic waves and the atmosphere is for greater than that for the electromagnetic waves, while the operational range and the speed of propagation of acoustic waves are far less than those for the electro-magnetic waves [89].

D. OPTICAL RADIATION

Optical radiation includes the ultraviolet (UV), visible and infrared (IR) portions of electromagnetic spectrum, that is, 10−2 µm to 103µm. The UV portion ranges from about 0.1-0.38 µm. The visible portion is approximately 0.38-0.76 µm in wavelength[90].

The air medium is where absorption and scattering occur when the radiation from the target and the background travels. The transmitted radiation energy, the, is received by the EO sensor[91]. Electro-magnetic spectrum distribution is shown in fig 4.

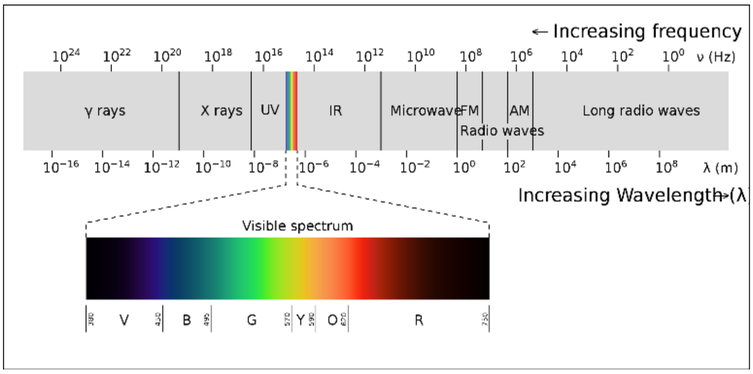

Fig. 4 ELECTRO-MAGNETIC SPECTRUM

VIII. CONCLUSION

In this article, radars, and its different types as well as image techniques have been detailed. We have discussed the scattering mechanism of the electro-magnetic waves that hit the target. Along with this, we have covered detection and ranging of radar system. Various radar functions such as velocity, angular direction, etc. have been discussed in this article. The change in frequency of signals that are received by the radar, also known as Doppler Effect and derivation of Doppler Frequency is also discussed in this paper. Radar is also used in imaging purposes, which has many applications from civilian to military. Various imaging techniques such as Synthetic and Inverse Synthetic Aperture Radar, Acoustic signals and Optical radiation have been briefed in this article. The use of these radars and their imaging techniques have become a popular technique due to their better accuracy as compared to other techniques. There are many military applications of these techniques.

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