KARMAVEER KAKASAHEB WAGH INSTITUTE OF ENGINEERING EDUCATION AND RESEARCH

MINI PROJECT REPORT

ON

"DRONE DETECTION AND NEUTRALIZATION"

SUBMITTED BY

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ELECTRONICS AND TELECOMMUNICATION ENGINEERING

YEAR 2021-2022

CERTIFICATE

This is to certify that project work entitled **“Drone detection & neutralization”** has been successfully completed during the academic year of 2021 – 2022 by the following students:

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This project confirms to the standards laid down by SPPU and has been completed in satisfactory manner as a partial fulfillment for the bachelor’s degree in Electronics & Telecommunication Engineering, SPPU.

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With all respect and gratitude, we would like to thank all the people who have helped us directly or indirectly for this project work.

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Thank you!

ABSTRACT

Anti-drone system is developed to neutralize enemy drone attacks including detection, Soft Kill for jamming the communication links of drone and laser-based hard kill to destroy the drone of enemy Drones.

Anti- drone system works on the concept of RF waves and the doppler shift. Drone mapping is used to detect the clutter for identifying UAVs and drones. It gives the clear frequency band ranges, altitude, azimuthal angle and elevation angle.

RF Analyzers consist of one or more antennas to receive radio waves and a processor to analyses the RF spectrum. They're used to try to detect radio communication between a drone and its controller. Some systems can identify the more common drone makes and models, and some can even identify the MAC addresses of the drone and controller (if the drone uses Wi-Fi for communication). This is especially useful for prosecution purposes – proving that a particular drone and controller were active.

Some high-end systems can also triangulate the drone and its controller when using multiple radio units spread far apart. Drone neutralization capabilities have enhanced the security infrastructure and also has helped in the technological edge over the enemy. DRDO has been developing the anti drone system which has created a platform for futuristic drone elimination techniques.

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CONTENT

Literature survey

This concept study is the result of a master's thesis in the product development programme at Chalmers. The thesis was proposed by Saab Surveillance as a possible market had been detected, possibly not adjacent to their core products. The study was carried out at Saab Surveillance's site in Gothenburg. The office is home to a large variety of competences and people with great technological knowledge house every floor of the building. I had no prior knowledge about radar technology but was drawn to this concept study as the important market need, need for creativity, width and hi-tech factors inspired me greatly.

The deep technological knowledge at Surveillance and integrated low volume products has resulted in Saab being a rather functional organization with some implications in speed of development which is likely common also for their competitors. Things like activity based work-environment and scrum meetings indicate a will for change towards lower functional barriers and facilitate effectivity in new product development (NPD). The company has during my study gone through a structural reorganization in most of the Gothenburg site's departments. Cross-functional teams were in the pipeline of being created and I could not help to think that this is all very relevant to my concepts study.

My task was to find a way in to a new market that seems to have great future potential. To do that I would have to focus on both identifying the market to see what opportunities there are, but also look at the company to understand what strengths could be utilized in creating a competitive product for a new market. I soon came to the conclusion that to have a chance of bringing something relevant to market means having to understand the need of customer better than competitors do.

Saab and its military competitors have had a way of developing products with long development time and sparse competitor analysis as an effect of military secrecy and large and information sensitive customers. I believe the secrecy of military applications have blocked new product development trends of modern times of getting real traction. If this is true, entering a new civil market could be hard and show a greater need of fast product development, extensive multi angle understanding of customer needs, and being able to maintain aim on a moving target during a development project

Introduction

Radio detection

Most objects—aircraft, ships, vehicles, buildings, features of the terrain, etc.—reflect radio waves, much as they do light. Radio waves and light are, in fact, the same thing—the flow of electromagnetic energy. In its most rudimentary form, a radar consists of five elements: a radio transmitter, a radio receiver tuned to the transmitter's frequency, two antennas, and a display (Fig. 1)

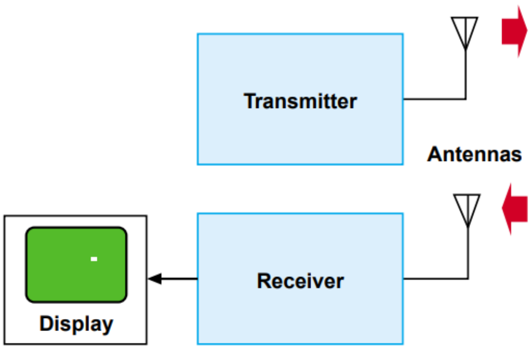

Figure1 In rudimentary form, a radar consists of five basic elements

To detect the presence of an object (target), the transmitter generates radio waves, which are radiated by one of the antennas. The receiver, meanwhile, listens for the "echoes" of these waves, which are picked up by the other antenna. If a target is detected, a blip indicating its location appears on the display. In practice, the transmitter and receiver generally share a common antenna (Fig. 2).

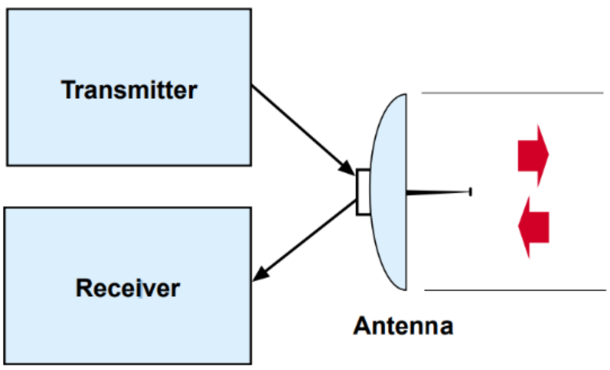

Figure 2: Single antenna time- shared by Transmitter & Receiver

To avoid problems of the transmitter interfering with reception, the radio waves are usually transmitted in pulses, and the receiver is turned off ("blanked") during transmission. The rate at which the pulses are transmitted is called the *pulse repetition frequency* (PRF). So that the radar can differentiate between targets in different directions as well as detect targets at greater ranges, the antenna concentrates the radiated energy into a narrow beam.

To find a target, the beam is systematically swept through the region in which targets are expected to appear. The path of the beam is called the search scan pattern. The region covered by the scan is called the scan volume or frame; the length of time the beam takes to scan the complete frame, *the frame time* (Fig. 3).

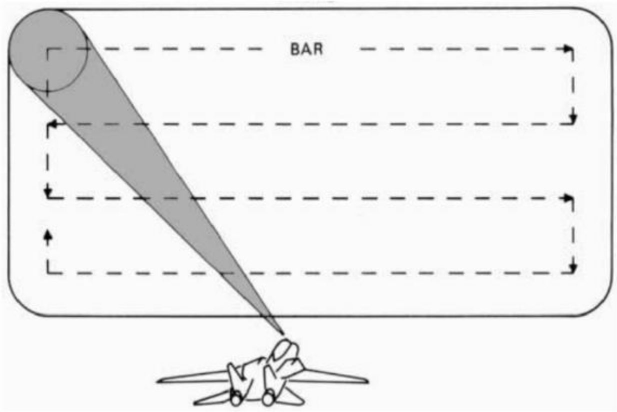

Figure 3: Typical search scan pattern for a fighter application. Number of bars and width and position of frame may be controlled by the operator

Like light, radio waves of the frequencies used by most airborne radars travel essentially in straight lines. Consequently, for a radar to receive echoes from a target, the target must be within the line of sight (Fig. 4)

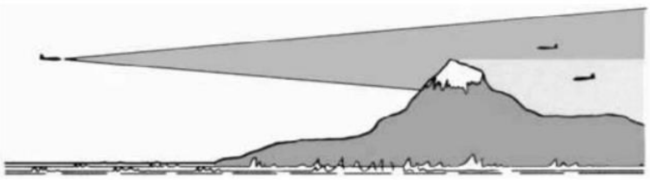

Figure 4: Line of sight

Even then, the target will not be detected unless its echoes are strong enough to be discerned above the background of electrical noise that invariable exists in the output of a receiver, or, above the background of simultaneously received echoes from the ground (called ground clutter) which in some situations may be substantially stronger than the noise. The strength of a target's echoes is inversely proportional to the target's range to the fourth power ($1/R4$). Therefore, as a distant target approaches, its echoes rapidly grow stronger.

The range at which they become strong enough to be detected depends upon a number of factors. Among the most important are these:

- Power of the transmitted waves
- Fraction of the time, τ/T, during which the power is transmitted
- Size of the antenna
- Reflecting characteristics of the target
- Length of time the target is in the antenna beam during each search scan
- Number of search scans in which the target appears
- Wavelength of the radio waves
- Strength of background noise or clutter

Determining target position

In most applications, it is not enough merely to know that a target is present. It is also necessary to know the target's location—its distance (range) and direction (angle).

Measuring Range:

Range may be determined by measuring the time the radio waves take to reach the target and return. Radio waves travel at essentially a constant speed— the speed of light. A target's range, therefore, is half the round-trip (two-way) transit time times the speed of light.

$$R = \frac{1}{2}\ \text{(Round-Trip Time)} \times \text{(Speed of Light)}$$
$$= \frac{1}{2} \times \frac{10}{1{,}000{,}000}\ \text{s} \times 300{,}000{,}000\ \text{m/s}$$
$$= 1.5\ \text{km}$$

The transit time is most simply measured by observing the time delay between transmission of a pulse and reception of the echo of that pulse— a technique called pulse-delay ranging. To radiate enough energy to detect distant targets, however, pulses must often be made very much wider. This dilemma may be resolved by compressing the echoes after they are received.

Radars which transmit a continuous wave (CW radars) or which transmit their pulses too close together for pulse delay ranging, measure range with a technique called *frequency-modulation* (FM) ranging. In it, the frequency of the transmitted wave is varied and range is determined by
observing the lag in time between this modulation and the corresponding modulation of the received echoes.

Measuring Direction:

In most airborne radars, direction is measured in terms of the angle between the line of sight to the target and a horizontal reference direction such as north, or the longitudinal reference axis of the aircraft's fuselage. This angle is usually resolved into its horizontal and vertical components. The horizontal component is called azimuth; the vertical component, elevation.

Where both azimuth and elevation are required, as for detecting and tracking an aircraft, the beam is given a more or less conical shape (Fig. 5). This is called a *pencil beam*. Typically, it is three or four degrees wide. Where only azimuth is required, as for long-range surveillance, mapping, or detecting targets on the ground, the beam may be given a fan shape.

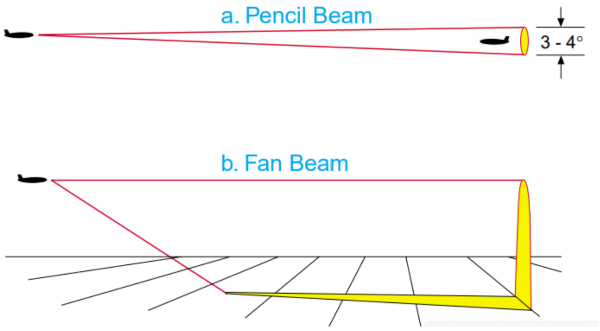

Figure 5: For detecting and tracking aircraft, a pencil beam is used. For long-range surveillance, mapping, or detecting targets on the ground, a fan beam may be used

Angular position may be measured with considerably greater precision than the width of the beam. For example, if echoes are received during a portion of the azimuth search scan extending from 30˚ to 34˚, the target's azimuth may be concluded to be very nearly 32˚.

Doppler effect

The Doppler effect or Doppler shift (or simply Doppler, when in context) is the change in frequency of a wave in relation to an observer who is moving relative to the wave source. It is named after the Austrian physicist Christian Doppler, who described the phenomenon in 1842. The classic example of the doppler effect is the change in pitch of a locomotive's whistle as it passes by. Today, a more common example is found in the roar of a racing car, which deepens as the car zooms by fig below.

A common example of the doppler shift. Motion of car crowds sound waves propagated ahead; spreads waves propagated behind.

Because of the doppler effect, the radio frequency of the echoes an airborne radar receives from an object is shifted relative to the frequency of the transmitter in proportion to the object's range rate. Since the range rates encountered by an airborne radar are a minuscule fraction of the speed of radio waves, the doppler shift—or doppler frequency as it is called—of even the most rapidly closing target is extremely slight. So slight that it shows up simply as a pulse-to-pulse shift in the radio frequency phase of the target's echoes. To measure the target's doppler frequency, therefore, the following two conditions must be met:

• At least several (and in some cases, a great many) successive echoes must be received from the target, and

• The first wavefront of each pulse must be separated from the last wavefront of the same polarity in the preceding pulse by a whole number of wavelengths— a quality called coherence. Coherence may be achieved by, in effect, cutting the radar's transmitted pulses from a continuous wave.

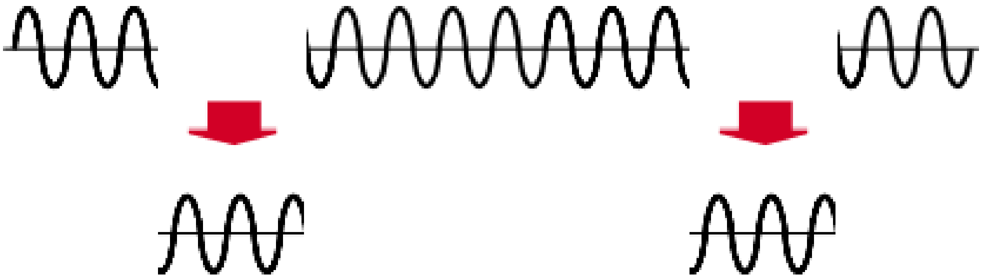

Fig. 6 Radio frequency phase of echoes

By sensing doppler frequencies, a radar can not only measure range rates directly, but also expand its capabilities in other respects. Chief among these is the substantial reduction, or in some cases complete elimination, of "clutter." The range rates of aircraft are generally quite different from the range rates of most points on the ground, as well as of rain and other stationary or slowly moving sources of unwanted return. By sensing doppler frequencies, therefore, a radar can differentiate echoes of aircraft from clutter and reject the clutter. This feature is called moving target indication (MTI). In some cases, it may also be called airborne moving target indication (AMTI) to differentiate it from the simpler MTI used in ground-based radars. MTI is of inestimable value in radars which must operate at low altitudes or look down in search of aircraft flying below them. The antenna beam then commonly intercepts the ground at the target's range. Without MTI, the target echoes would be lost in the ground return.

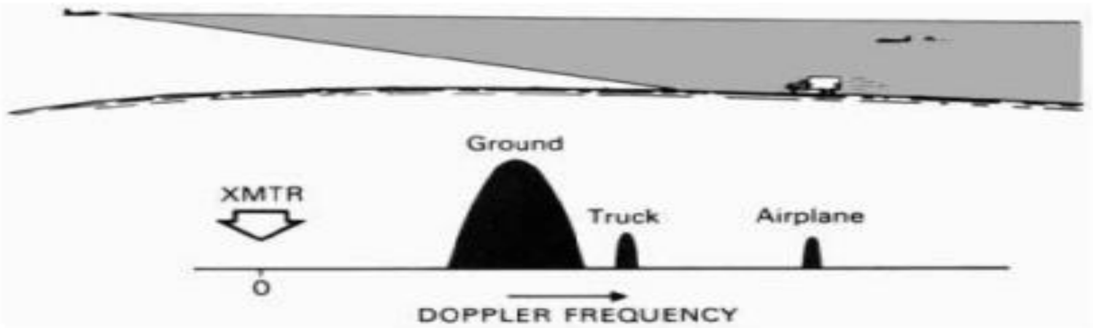

Fig.7 Doppler Frequency

With MTI, echoes from aircraft and moving vehicles on the ground are separated from ground clutter on the basis of the differences in their doppler frequencies. Generally, echoes from aircraft and echoes from moving vehicles on the ground similarly may be differentiated as a result of the ground vehicles' lower speed.

MTI can also be of great value when flying at higher altitudes and looking straight ahead. For even then, the lower edge of the beam may intercept the ground at long ranges. A radar can similarly isolate the echoes of moving vehicles on the ground. In some situations where MTI is used, the abundance of moving vehicles on the ground can make aircraft difficult to spot. But echoes from aircraft and echoes from vehicles on the ground can usually be differentiated by virtue of differences in closing rates, due to the ground vehicles' lower speeds. Where desired, by sensing the doppler shift, a radar can measure its own velocity. For this, the antenna beam is generally pointed ahead and down at a shallow angle. The echoes from the point at which the beam intercepts the ground are then isolated and their doppler shift is measured. By sequentially making several such measurements at different azimuth and elevation angles, the aircraft's horizontal ground speed can be accurately computed.

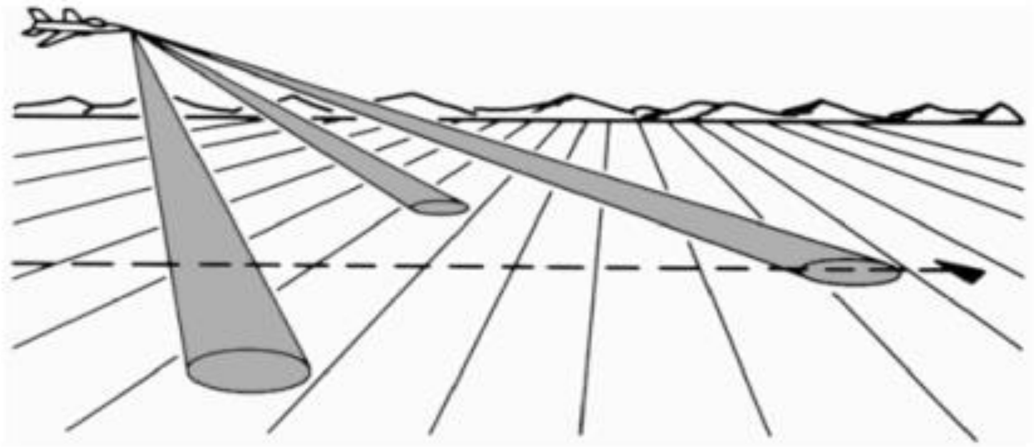

Fig.8 Radar's own velocity may be computed from doppler frequencies of three or more points on the ground at known angles.

Ground Mapping

The radio waves transmitted by a radar are scattered back in the direction of the radar in different amounts by different objects—little from smooth surfaces such as lakes and roads, more from farm lands and brush, and heavily from most man-made structures. Thus, by displaying the differences in the intensities of the received echoes when the antenna beam is swept across the ground, it is possible to produce a pictorial map of the terrain, called a ground map. Radar maps differ from aerial photographs and road maps in several fundamental respects: In the first place, because of the difference in wavelengths, the relative reflectivity of the various features of the terrain may be quite different for radio waves than for visible light. Consequently, what is bright in a photograph may not be bright in a radar map, and vice versa. In addition, unlike road maps, radar maps contain shadows, may be distorted, and unless special measures are taken to improve azimuth resolution, may show very little detail. Shadows are produced whenever the transmitted waves are intercepted—in part or in whole—by hills, mountains, or other obstructions. The effect can be visualized by imagining that you are looking directly down on a relief map illuminated by a single light source at the radar's location. Shadowing is minimal if the terrain is reasonably flat or if the radar is looking down at a fairly steep angle.

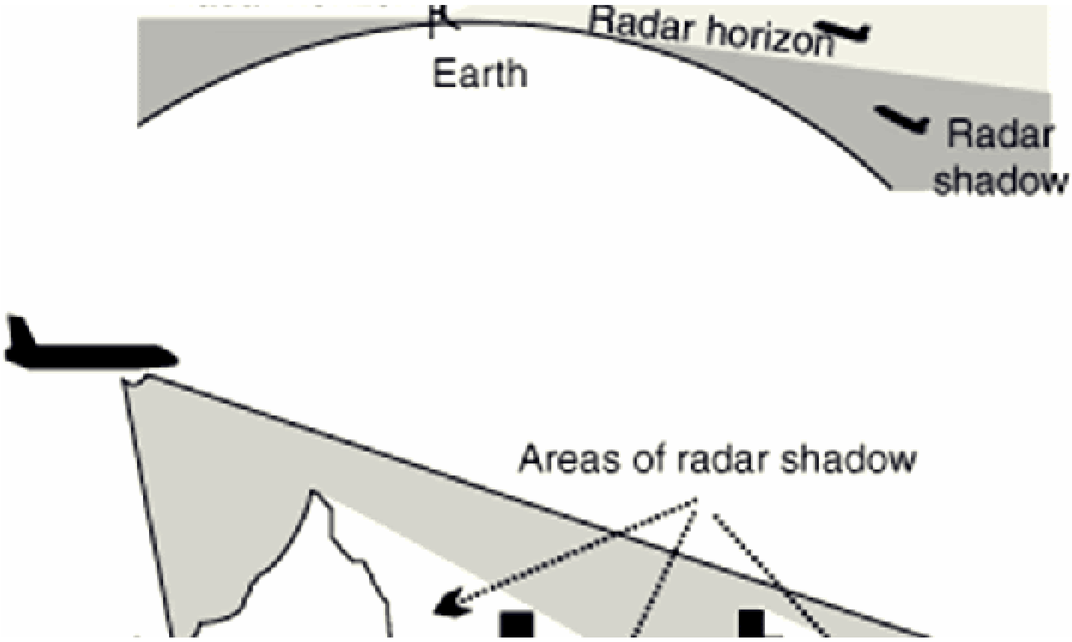

Fig.9 Shadows leave holes in radar maps. At steep lookdown angles, shadowing is minimized.

Distortion arises, however, if the lookdown angle is large. Since the radar measures distance in terms of slant range, the apparent horizontal distance between two points at the same azimuth is foreshortened. Drone mapping is actually an aerial survey conducted by drone and specialist cameras which can include RGB, multispectral, thermal or LiDAR sensors. LiDAR is particularly effective for detecting small objects during drone mapping. This method enables collection if highly accurate data, extremely quickly. If the terrain is sloping, two points separated by a small horizontal distance can, in the extreme, be mapped as a single point. Usually, the foreshortening can be corrected on the basis of the lookdown angle, before the map is displayed. The degree of detail provided by a radar map depends upon the ability of the radar to separate (resolve) closely spaced objects in range and azimuth. Range resolution is limited primarily by the width of the radar's pulses.

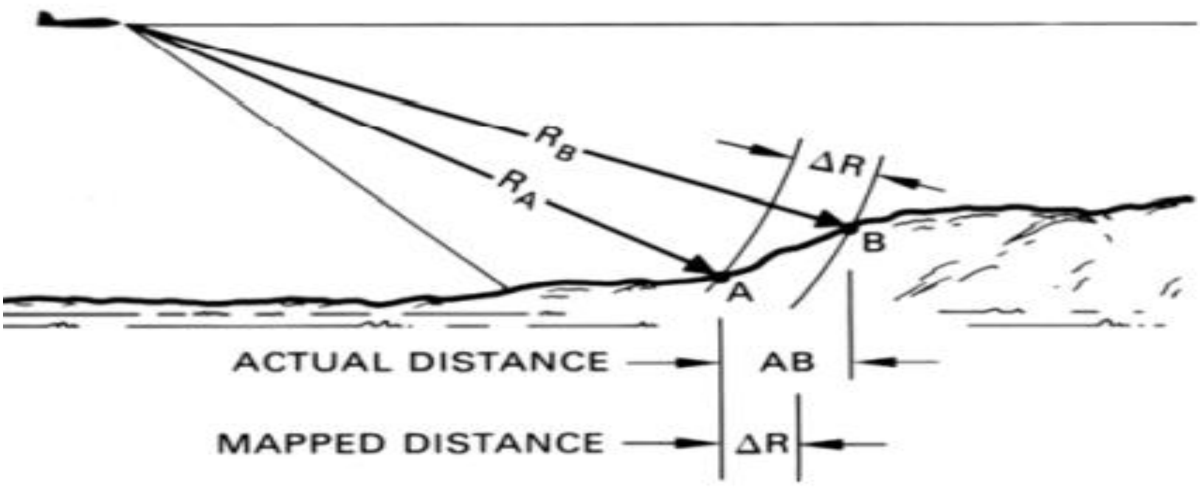

Fig.10 At steep lookdown angles, mapped distances are foreshortened. Except for distortion due to slope of the ground, foreshortening may be corrected before map

By transmitting wide pulses and employing large amounts of pulse compression, the radar may obtain strong returns even from very long ranges and achieve range resolution as fine as a foot or so. Fine azimuth resolution is not so easily obtained. In conventional (real-beam) ground mapping, azimuth resolution is determined by the width of the antenna beam.

With conventional mapping, dimensions of resolution cell are determined by pulse width and width of the antenna beam

With a beamwidth of 3º, for example, at a range of 10 miles azimuth resolution of a real-beam map may be no finer than half a mile. Azimuth resolution may be improved by operating at higher frequencies or by making the antenna larger. But if exceptionally high frequencies are used, detection ranges are reduced by atmospheric attenuation, and there are practical limitations on how large an antenna most aircraft can accommodate. However, an antenna of almost any length can by synthesized with a technique called synthetic array radar (or synthetic aperture radar), SAR.

General Range Equation

When the radar antenna is trained on a target, the energy received from the target during any one integration time is roughly.

$$\text{Received Signal Energy} = \frac{P_{avg}\, G\, \sigma\, A_e\, t_{int}}{4\Pi^2 R^4}$$

where,
Pavg = average transmitted
power G = antenna gain
σ = radar cross section of target
Ae = effective antenna area
tint = integration time
R = range

For a certain target to be detected this received energy plus accompanying noise energy must exceed a certain threshold value.

On average, the minimum energy that a signal must have to cross the detection threshold is the difference between the detection threshold and the mean level of the noise. This difference is commonly denoted by S_{min}.

Minimum detectable signal energy = S_{min}

Assuming perfect integration the maximum range at which a given target will be detected is the range at which the received signal energy becomes equal to S_{min}.

Maximum detectable range is given by:

$$R_{max} = \sqrt[4]{\frac{P_{avg}\, G\, \sigma\, A_e\, t_{int}}{(4\Pi)^2 S_{min}}}$$

This concept is explained with the help of figure below:

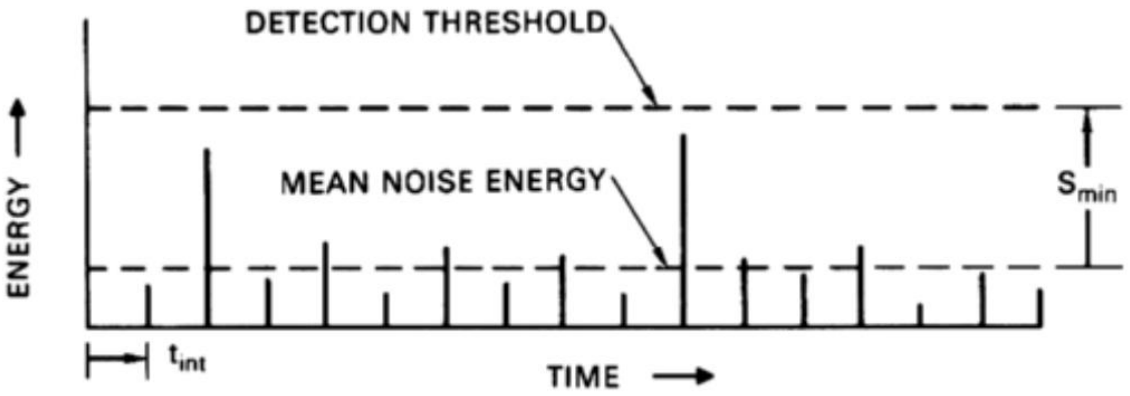

Fig.11 Integrated noise energy at end of successive integration times tint. On average for a target to be detected integrated signal energy must equal Smin.

Integrated noise energy at end of successive integration times tint. On average for a target to be detected integrated signal energy must equal Smin.

But it is very important to remember that this equation applies only when the antenna is continuously trained on the target and the target is in the center of the mainlobe, i.e., when a target is being spotlighted.
if we replace tot with the pulse width, τ, and Pavg with the peak power, P, the equation gives the range for single-pulse detection.

Then Max detection range is given by:

$$R_{max} = \sqrt[4]{\frac{P\, G\, \sigma\, A_e\, \tau}{4\Pi)^2\, S_{min}}}$$

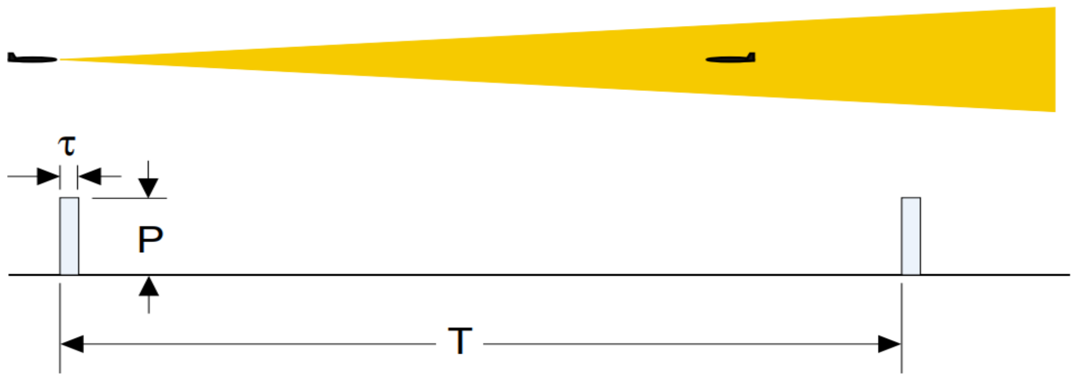

Fig.12 Range Equation

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Range equation can be applied to non doppler radars by substituting pulse width for tint and peak power P for Pavg .

Now let us talk about the Omissions of this equation:

- Absorption and scattering in the atmosphere.
- Reduction in signal energy due to the target not necessarily being centered in the path of the scanning antenna beam (this is called elevation beamshape loss).
- Losses due to imperfect IF-filter matching—some noise being unnecessarily passed and/or some signal energy being rejected.
- Loss due to the target not necessarily being centered in a doppler filter.
- Degradation of signal-to-noise ratio due to imperfect integration of the target return.
- Effects of system degradation in the field.

One of the very important losses not accounted for by the simple range equation is the atmospheric attenuation.

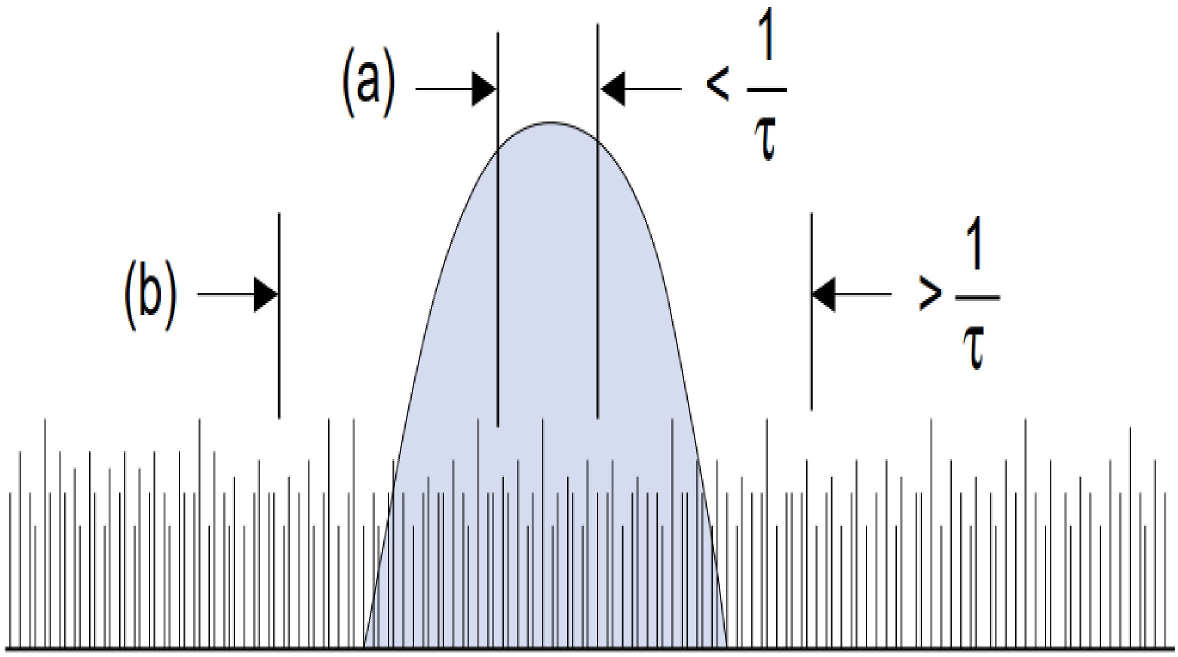

Fig.13 IF – filter mismatch. A) some signal being rejected that is stronger than accompanying noise. B) Some noise being passed that it is stronger than accompanying signal.

Fluctuations in Radar cross system

If we think of reasons of fluctuations we can see that if we assume a target specimen as a collection of large number of individual scatterers, the extent to which the scatter from these adds up or cancels in direction of radar depends on their relative phases.

If the phases are more or less the same, the backscatter will add up to a large sum. If they are not, the sum may be comparatively small.

The relative phases depend upon the instantaneous distances in wavelengths of the reflectors from radars. Because of round trip nature of transmission as we have seen earlier difference in distance of one-fourth wavelength makes a difference in phase of 180^0.

As wavelength may be very short relatively small changes in target even in vibration can cause target return to scintillate like the light from the star.

As the configuration of many targets is radically different when viewed from different directions, larger changes in aspect may produce strong peaks or deep fades.

As the relative phases of returns from individuals depend on wavelength target aspects for which fades will occur will be slightly different for different wavelengths.

One way of getting around the problem of target fading, therefore, is to switch periodically from one to another several different radio frequencies.

This is in other words called as Frequency Diversity.

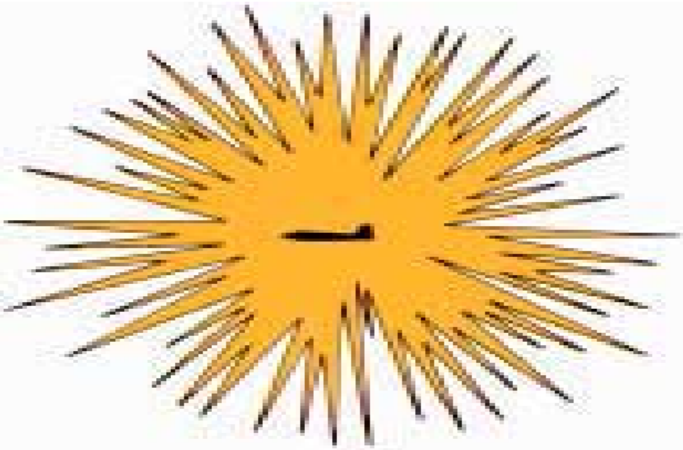

Fig.13 Polar plot of radar cross section.

Acoustic detection

The word acoustic means science concerned with production, control, transmission, reception, and effects of sound. The term is derived from the Greek word acoustic meaning heard.
The acoustic detection method detects presence of objects(here a drone) by the sound created by that object.
Drone Shield acoustic sensors with advanced detection technology are capable of sensing drones even if they are invisible to radars or lack radio-frequency links.
Acoustic sensors are used by security forces in order to identify unauthorized penetration of drones into protected zones. The sensor network provides real-time alerts as well as collection of digital evidence.
UAV detection sensors work according to the following scheme: Listening-Analysis-Identification-Alerts.

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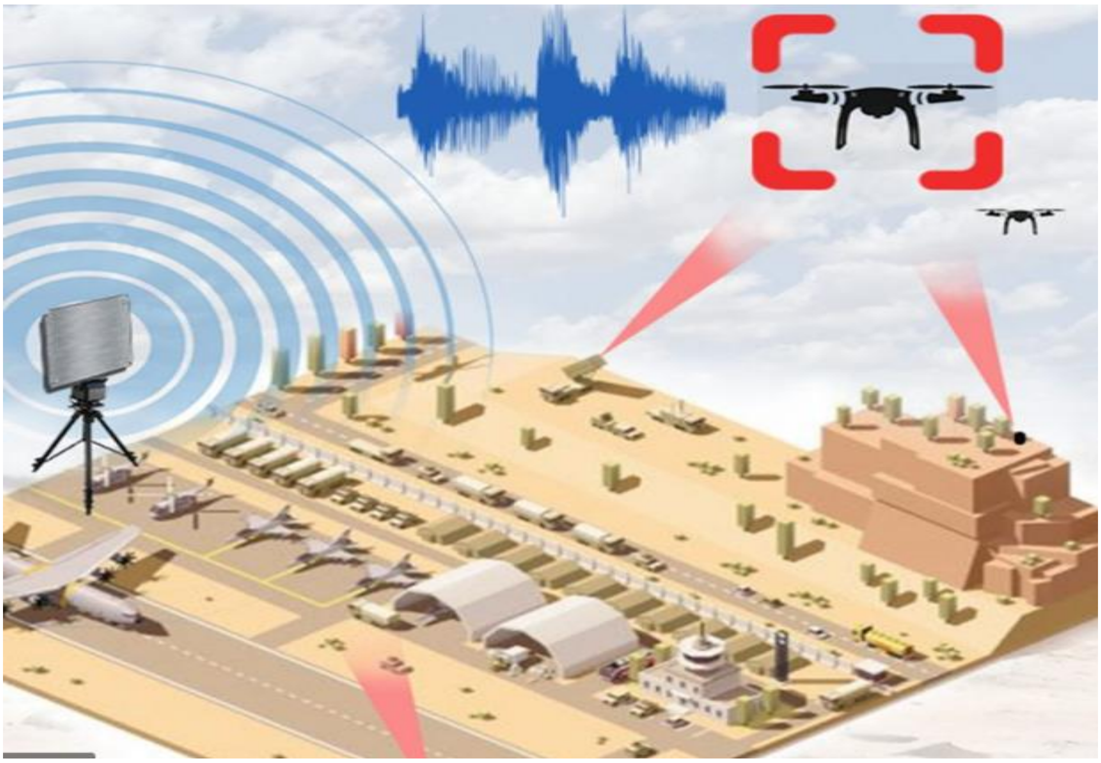


Fig 14 Acoustic Detection System

Acoustic detection system

Listening: Drone detection sensors recognize unique sound signatures of different UAV types. In other words, the acoustic sensors listen to surrounding activities in real time and automatically take sound samples in case they sense UAV activity nearby.
Analysis: UAS detection sensors compare the sound samples with the acoustic signatures from the built-in database. If the match is found, the drone acoustic detection system records identifying information and issues an automatic alert.
Identification: UAV acoustic detection system has an extensive database of drone acoustic signatures, which allows to distinguish UAVs from other noise sources with high level of accuracy and low level of false alarms.

Alerts: Instantaneous drone threat alerts can be delivered via email, SMS, existing video systems or incident management systems as well as visual interface with real-time reflection of surrounding acoustic activities.

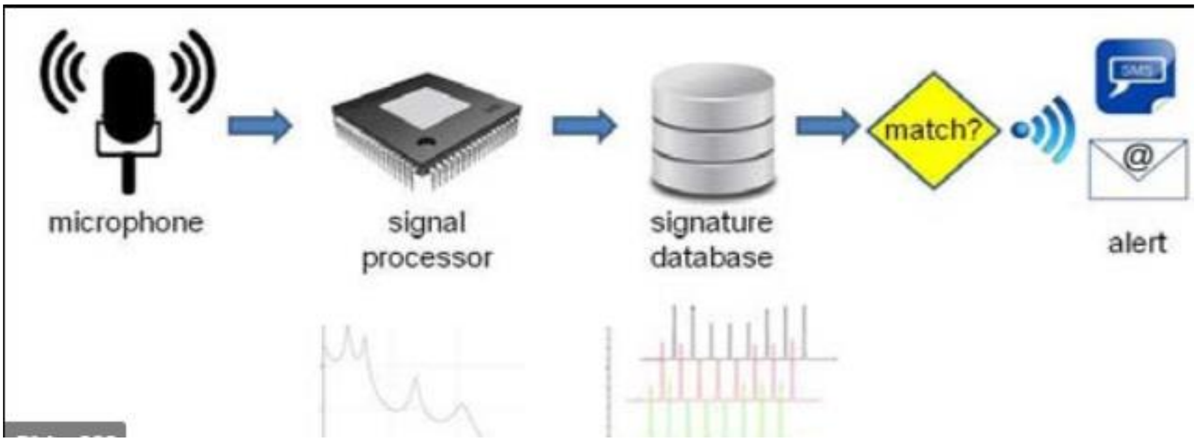


Fig 15 Acoustic Detection System

Main benefits of drone acoustic detection:

- Live monitoring of surrounding activities and instant threat alerts
- Fast and easy integration with other security systems
- Price affordability: from single-sensor residential protection to sensor networks for enterprise-level installations
- User-friendly interface with remote access
- Detection of UAVs with lack of radio-frequency links or invisible to radars

Applications:

- Private residences
- Airports
- Industrial premises
- Prisons
- Power stations
- Border Control
- Military bases
- Strategic sites

Drone Shield UAV detection sensors are represented by two types of acoustic sensors
1. Long Range Acoustic Sensors   2. Omnidirectional Acoustic Sensors.

Doppler Effect

By sensing doppler frequencies, a radar not only can measure range rates, but also can separate target echoes from clutter, or produce high resolution ground maps. Since these are important functions of many of today's airborne radars, one of the keys to understanding their operation is a good understanding of the Doppler Effect.

What is DOPPLER EFFECT?

The Doppler Effect is a shift in the frequency of a wave radiated, reflected, or received by an object in motion.

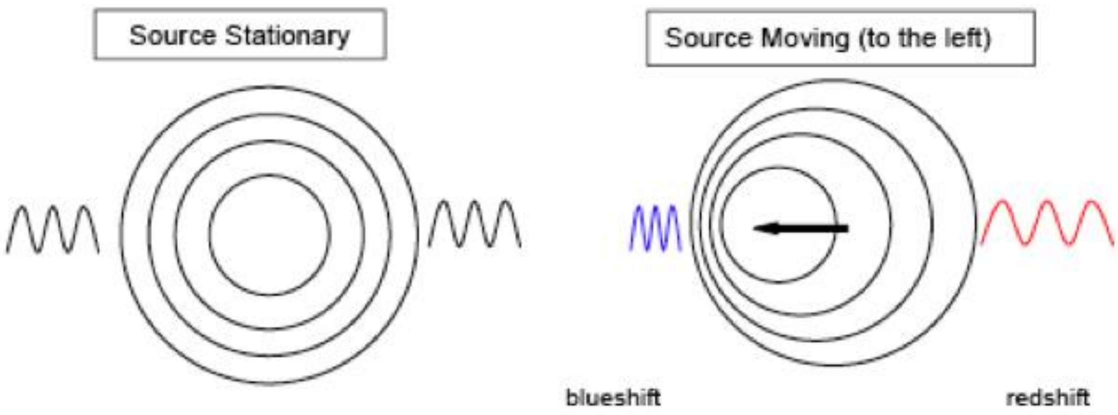


Fig. 16 Doppler Effect

As illustrated in fig, a wave radiated from a point source is compressed in the direction of motion and is spread out in the opposite direction. In both cases, the greater the object's speed, the greater the effect will be. Only at right angles to the motion is the wave unaffected. Since frequency is inversely proportional to wavelength, the more compressed the wave is, the higher its frequency is, and vice versa. Therefore, the frequency of the wave is shifted in direct proportion to the object's velocity. In the case of a radar, Doppler shifts are produced by the relative motion of the radar and the objects from which the radar's radio waves are reflected. If the distance between the radar and a reflecting object is decreasing, the waves are compressed. Their wavelength is shortened and their frequency is increased. If the distance is increasing, the effect is just the opposite.

With ground-based radars, any relative motion is due entirely to movement of the radar's targets. Return from the ground has no Doppler shift. Differentiating between ground clutter and the echoes of moving targets, therefore, is comparatively easy.

With airborne radars, on the other hand, the relative motion may be due to the motion of either the radar or the targets, or both. Except in such aircraft as hovering helicopters, the radar is always in motion. Consequently, both target echoes and ground return have doppler shifts. This greatly complicates the task of separating target echoes from ground clutter. A radar can differentiate between the two only on the basis of differences in the magnitudes of their Doppler shifts.

In general terms, mathematically, for every half wavelength per second that a target's range decreases, the radio frequency phase of the received echo advances by the equivalent of one whole cycle per second.

Doppler frequency of a target,

$$\therefore f_d = \frac{-\dot{R}}{\lambda/2} = \frac{-2\dot{R}}{\lambda}$$

Fig. 17 Doppler frequency equation

Where, f_d = doppler shift (positive for decreasing R)

R = radial component of relative velocity

λ = wavelength.

A radar signal is a sinusoidal wave of RF (radio frequency) energy that is transmitted in the air like ripples on water. The wavelength is the distance (usually in centimeters) over which the wave repeats. It is equal to the inverse of the transmitted frequency of the radar. A Doppler radar monitors the reflected RF waves from objects over time. The typical pulsed radar system will transmit bursts (pulses) of RF energy. The time between the pulses is used to measure the range to objects. The pulsed-Doppler radar transmits groups of pulses (i.e., the radar dwell), and then monitors changes in frequency across those pulses. The changes in the frequency are due to the stretching and compressing of the waves of the radar signal by the movement of the object away from or toward the radar, respectively. This is identical to the change of tone due to the stretching and compression of sound waves from the horn of a car that passes by an observer. A Fast-Fourier Transform (a mathematical algorithm) applied to the digitized reflected radar signal supplies a measure of all frequency changes from the object, and frequency can be converted to radial velocities. Radial velocities are the speeds of objects in the direction of the radar. As long as the proper waveform is used, all velocities present on the object will be measured. For example, for a human the main body velocity (from the torso in this case) as well as the arm and leg radial velocities will be measured. If you watch the Doppler response long enough, the gait of a person can be established.

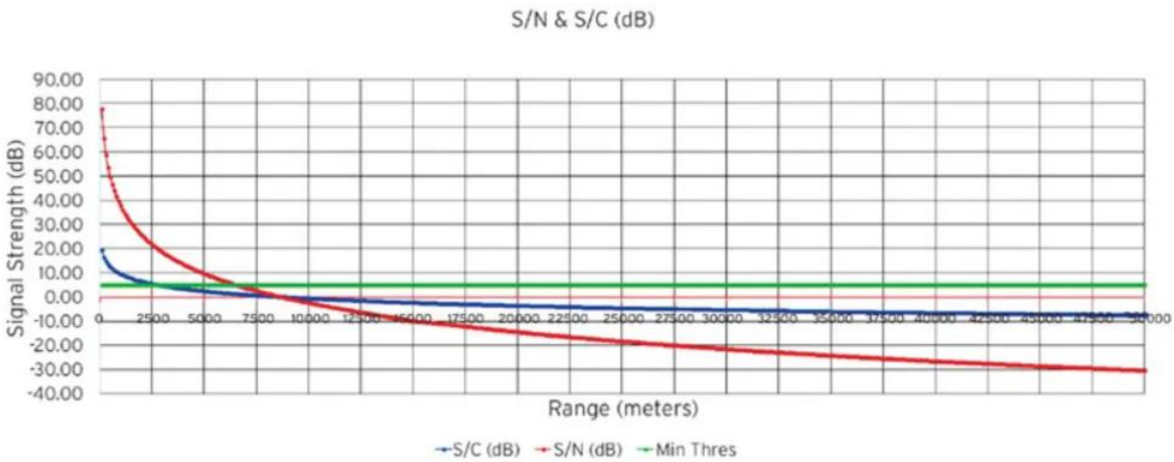


Fig .18 In this graph, the pulse width of the radar is 50 nanoseconds. The blue line is S/C, the red line is S/N, and the green line represents the threshold condition for comparing the two curves. In this case, the green curve is set to 5 dB above the noise floor. This radar's detection range is limited by the S/C to about 2.5 km. Since S/N is not the issue, the pulse width should be shortened. (Ref – aerodefensetech.com)

The Doppler velocities from other than the main body are often referred to as micro-Doppler signatures. For quadcopter drones, the responses from the blades and motors constitutes the micro-Doppler signatures. With sufficient testing, a database of signatures unique to each drone can be generated. Each future Doppler signature measured by that radar can be compared to that database for drone characterization. The stored signatures can also be used to eliminate objects that are not drone-like.

If a radar can detect a small drone, it will also detect birds. The main-body signature of a bird can resemble that of a drone, especially for larger birds that are flying in straight-line paths or spiral-ing slowly on thermal updrafts. The micro-Doppler signature, however, will be substantially different.

Characterization of drones using micro-Doppler requires:

- The correct frequency, PRF (pulse repetition frequency), and pulse width;
- A sufficient number of pulses to obtain the micro-Doppler components;
- High sampling rates in the analog-to-digital hardware;
- FFT analysis of data collected over a group of pulses (the dwell), and clutter rejection algorithms that operate in the frequency domain.

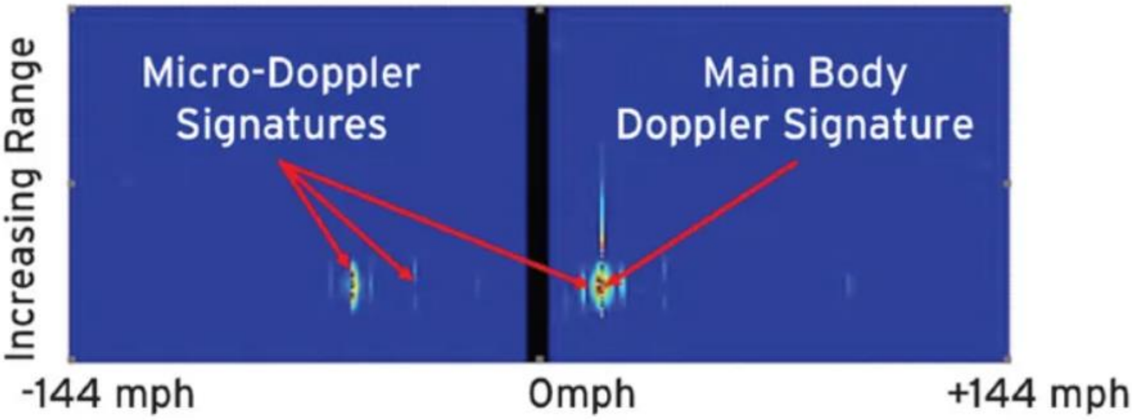


Fig .19 This is a Doppler-Time-Intensity plot for a pulsed-Doppler radar. The plot shows all Doppler signatures from one aspect of a drone. The main body is clearly visible. The micro-Doppler signatures are also present. Most environmental reflections from vegetation and weather appear close to 0 mph and are ignored. (Ref – aerodefensetech.com)

The number of pulses determine the Doppler resolution of a radar. An X-Band radar with 256 pulses in the dwell will have a Doppler resolution of 7.8125 Hertz, which is equal to a speed resolution of 0.283 mph. Drop the number of pulses to 128, and the speed resolution goes up to 0.567 mph. As the speed resolution decreases, the micro-Doppler improves. If the speed resolution is too large, the main body signature dominates and the ability to characterize diminishes to unusable levels.

Once the parameters are set on the pulsed-Doppler radar, all the Doppler signatures from the drone may be measured. By creating a database of Doppler signatures (as in Figure) from a wide variety of drone types and aspect angles, the radar will easily characterize drones and eliminate all other false-positives, such as bird signatures.

Interception

This chapter begins with a discussion of various methods of stopping an intruder UAV. Trajectory planning and interception algorithms based on different situations and configurations are then presented, and finally, possible solutions for target tracking are evaluated.

Kinetic attack

The mode of attack which requires almost no additional equipment is a kinetic attack, during which the interceptor tries to disable the target by crashing into it at high velocity. The interceptor can be equipped with protective elements which can cover the delicate electronics and shield the propellers and motors, but it would be still probable that the interceptor itself could get damaged during this scenario. If the attack is successful, the target, and in some cases, even the interceptor, will fall from the air and might damage property on injure somebody on the ground.

In terms of control, localization, and planning, this mode of attack is the most difficult to implement, as it requires a direct hit of a relatively small target with a relatively small interceptor. The interceptor needs to be able to perform agile maneuvers and preferably be able to fly faster than the target. This mode of attack can be used as a backup if other methods fail and the neutralization of the target is critical, the kinetic attack can be deployed as a last resort.

Trajectory planning

In this section, various methods of trajectory planning for the interceptor will be discussed. These methods will later be combined to produce a robust interception trajectory planner. At first, the kinetic attack scenario, will be considered, as it is the most challenging in terms of control and trajectory planning. Trajectory planner for kinetic attack can be later relatively easily modified for the other scenarios, and it can also be used as a backup if other approaches fail. It is also assumed for now that the measurement of the target position is available at all times to the interceptor.

Stationary target

In the simplest scenario, the target is hovering and staying in the same position. This behavior is not uncommon with operators of camera-equipped drones who are surveying an area. The estimator, produces an estimate of the position of the target ,

$$\mathbf{x}_e = \begin{bmatrix} x_e \\ y_e \\ z_e \end{bmatrix},$$

which is used for interceptor trajectory planning. First, yaw angle φt at which the target is "seen" by the interceptor is calculated as follows:

$$\varphi t = \text{atan2}(ye - y, xe - x)$$

The trajectory planning algorithm can run at a high frequency, up to the frequency of the MPC loop itself, to keep the planned trajectory up to date with the latest target position estimate. Notice that the Z coordinate of every sample of the planned trajectory is the same as the current estimated Z coordinate of the target, to force the Interceptor to fly at the same altitude level. This not only forces the interceptor to prioritize changes in altitude, which are more energy demanding than changes in X and Y, it will also keep the target in the FOV of a potential onboard tracking camera. The produced trajectory will probably be infeasible, not only because of the discontinuity in the Z coordinate but also because the current horizontal velocity vector of the interceptor may not be in line with the planned trajectory.

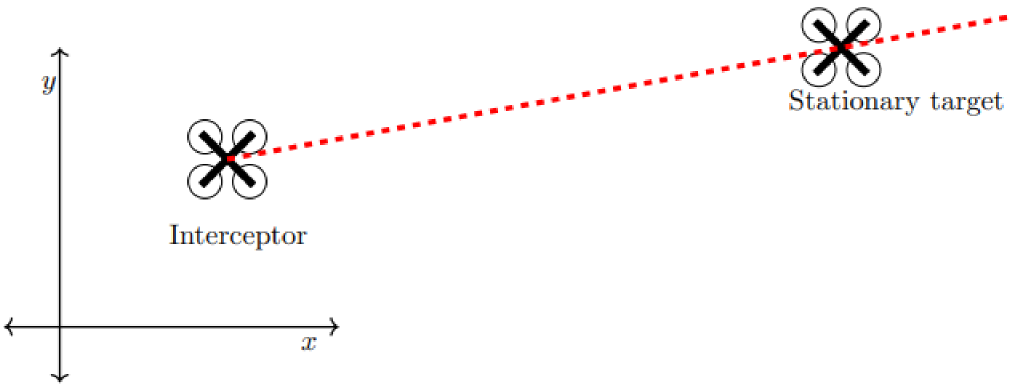


Fig. 20 Stationary target in Kinetic technique

If the interceptor misses the target during the first attack run, there is no need to change anything in the planning algorithm, as it will simply plan the new trajectory from the new position of the interceptor. The interceptor will get carried away by its residual velocity from the previous attack run. This will allow it to start the next attack run from a sufficient distance, to pick up enough horizontal velocity to eliminate the target.

Dynamic target

A similar approach in trajectory planning can be used to intercept moving targets, but the algorithm has to be modified to plan interception trajectories not through the current position of the target, but through an estimated future target position. The future trajectory of the target can be estimated by taking the current estimated state of the target, produced by the estimator, which was described in chapter 2 and applying the state transition matrix A, shown in equation 1, to it. We can obtain estimates of the future states as follows:

$$xe[t+1] = Axe[t] ,$$

where xe[t] is the estimated state of the target at a time sample t. The time interval Δt in the A matrix can be changed, to produce estimates at different sampling frequencies. By applying the state transition matrix A over and over, future states can be estimated and combined into an estimated future trajectory of the target. With this estimate, an interception point can be calculated given the current position of the interceptor and its known dynamic limitations. The process for calculating the estimated point of interception is shown in algorithm 2. Once the estimated interception point is calculated, it can be used to plan a straight trajectory from the current position of the interceptor through the estimated point of interception. To plan this trajectory, algorithm 1 is used, only the estimated position of the target is substituted with the estimated point of interception. The resulting interception trajectory for dynamic target is visualized.

Target following

This approach will not produce an intercepting trajectory, but it will plan a trajectory for the interceptor to follow the flying target. The interceptor can then switch to a direct attack, after reaching a position behind the target and matching velocities. Attacking from behind of the target can be very beneficial, as the target might be equipped with an onboard camera, which is used by the operator for video piloting (also called FPV - first person view). This camera is usually pointed in the direction of the flight, and it will therefore not capture the interceptor approaching from behind. If the interceptor is using an onboard camera to detect the target, the position of the target in the camera picture can be measured with a relatively good accuracy, however the distance between the interceptor and the target is much harder to determine, mostly because the actual size of the target is not know, therefore it cannot be compared to the size of the target in the camera picture do determine the distance. This means that the vector from to the interceptor to the target can be measured with better accuracy than the distance to the target. Attacking from behind of the target will reduce the influence of the error in the distance measurement, as the planned interception trajectory is close to being in line with the vector from the interceptor to the target and therefore reducing the influence of the error. In a similar fashion, error in the estimated velocity of the target can also be partially compensated for by attacking from behind.

To plan a target following trajectory, the past and the estimated future trajectory of the target can be used.

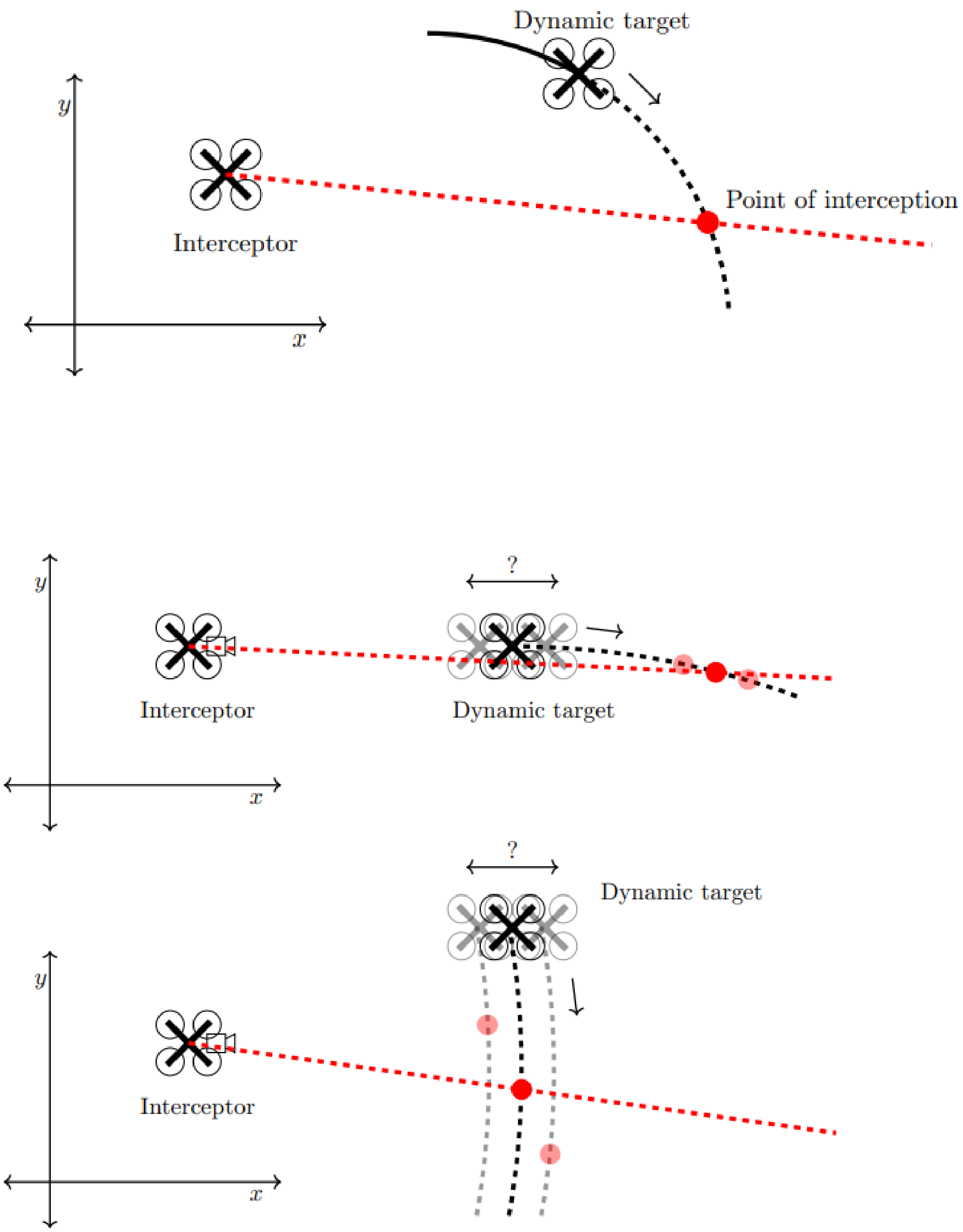


Fig. 21 Dynamic target in kinetic technique

The uncertainty in distance measurement caused by the onboard tracking camera is compensated for by attacking from behind. The interceptor is able to fly much closer to the optimal point of interception, even when there is high uncertainty in the distance measurement.

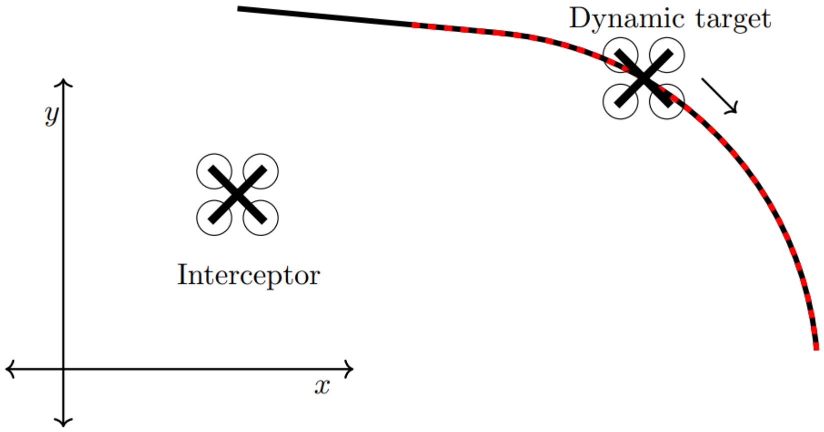
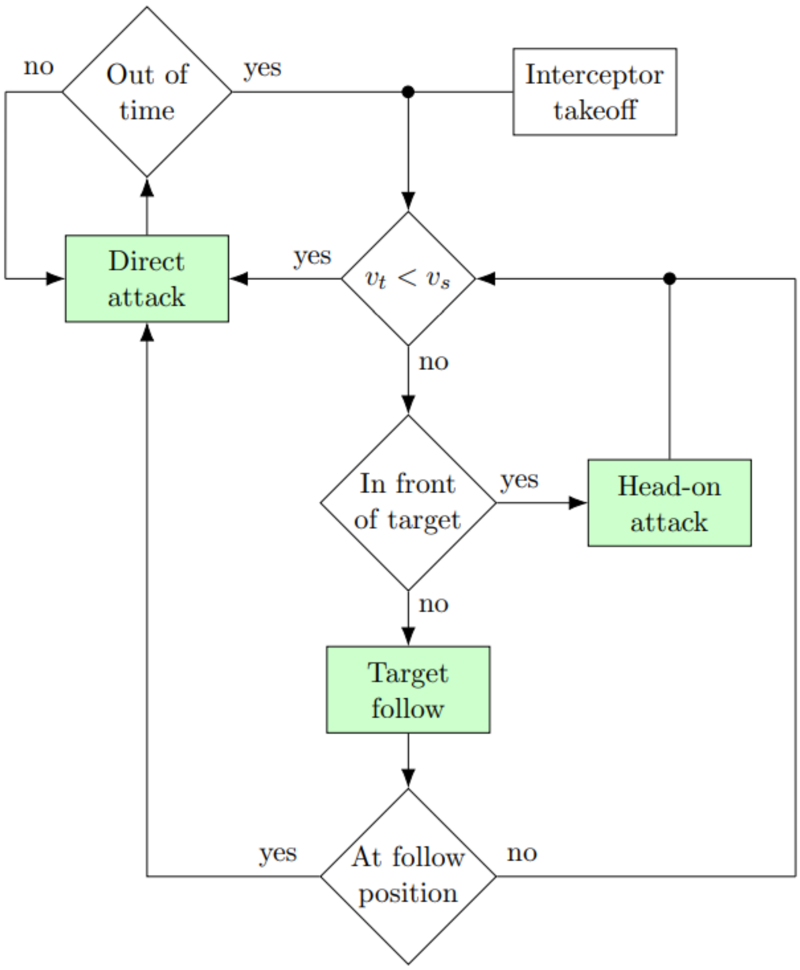


Fig. 22 Dynamic Targe Neutralized

FLOW CHART:


no
Out of time
yes
Interceptor takeoff
Direct attack
yes
$v_t < v_s$
no
In front of target
yes
Head-on attack
no
Target follow
yes
At follow position
no

Other approaches to target elimination

The above-described interception algorithm is designed for kinetic attack, but it can be modified for the passive net or the net launcher. If the interceptor is using the passive net, the only required change is to add an altitude offset to all the planned trajectories, depending on the height and mounting point of the net. The yaw angle of the interceptor has to be also considered, to ensure that the net will hit the target with its broad side. The yaw angle for each time sample t of the trajectory is calculated as follows: φ[t] = atan2(ye[t] − yi[t] , xe[t] − xi[t]), (26) where ye[t] and xe[t] is the estimated position of the target at a time sample t and xi[t] and yi[t] is the planned position of the interceptor at a time sample t. If the interceptor is less than 1 meter from the estimated position of the target, the yaw angle is kept at the last calculated value, to prevent it from jumping 180° as the interceptor flies over the target. If the interceptor is using the net launcher, the interception algorithm has to be significantly modified. The position of the following point (xp[m]) is

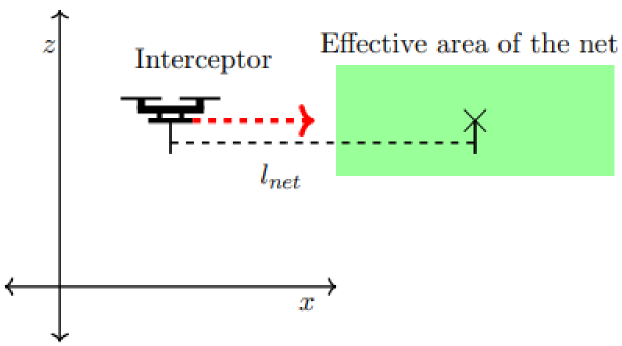


Figure 19: Effective space of the launched net (green) and ideal distance from the target l_{net}.

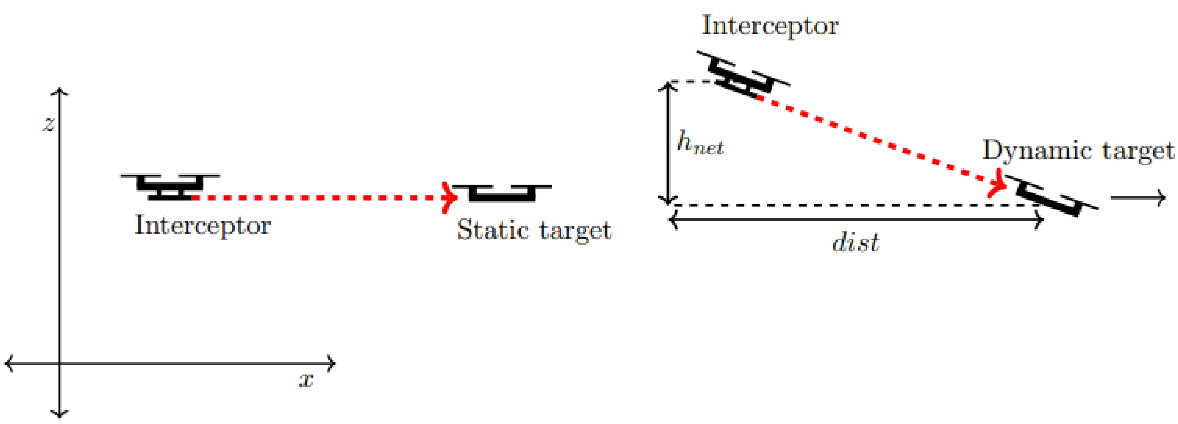


Fig.23 Interception

adjusted so that the following point is an ideal point from which the net should be launched at the target. The net should be launched from a sufficient distance to allow the net to unravel itself to its full size. We can define a 3-dimensional space in front of the interceptor, where the net can effectively hit the target. For example, the typical net launcher can fire a 3×3 meter net at a distance of up to 10 meters, so the effective space can be defined as a cylinder with a diameter of 2 meters, spanning from three to seven meters in front of the interceptor. In this space, the net is fully unraveled, and it is still flying at high velocity, ensuring target hit. Therefore, if the target is inside of this defined effective space, the net should be launched. In the ideal case, the target should be in the center of this space, at an ideal distance lnet from the interceptor, which is shown in figure 19 Similarly, with the passive net scenario, the yaw angle of the interceptor has to be set to aim the launcher at the target, using the same equation 26. Additionally, if the launcher is mounted directly to the frame of the interceptor, the pitch angle θ has to be considered when aiming the net launcher, which is illustrated in figure 20. To compensate for the pitch angle θ of the interceptor, the following point xp[m] has to be offset both in altitude (hnet) and in horizontal distance (parameter dist in algorithm 3),to keep the 3D distance between the target and the interceptor close to the optimal lnet. The offsets are calculated as follows: hnet = cos(θ)dist, distc = sin(θ)dist, (27) where distc is the new desired horizontal following distance behind the target, used as an input in algorithm 3. The pitch angle of the interceptor is mainly influenced by three factors: interceptor's velocity, it's air resistance and wind. Pitch angle needed to fly at a certain velocity can be determined beforehand, by calculation or experimentation. Those values can be stored in a look-up table, and desired offsets hnet and distc can be added to the reference trajectory in the planning phase, based on the desired velocity of the interceptor. This allows the MPC tracker to fly the trajectory with the offsets in mind from the start. During flight, the actual pitch angle of the interceptor will vary from the predetermined value, because of wind and other factors. This is compensated for by adding another correction on top of the predetermined one, based on the current actual pitch angle. The magnitude of this correction will be much smaller as most of the correcting is already accounted for by the predetermined correction.

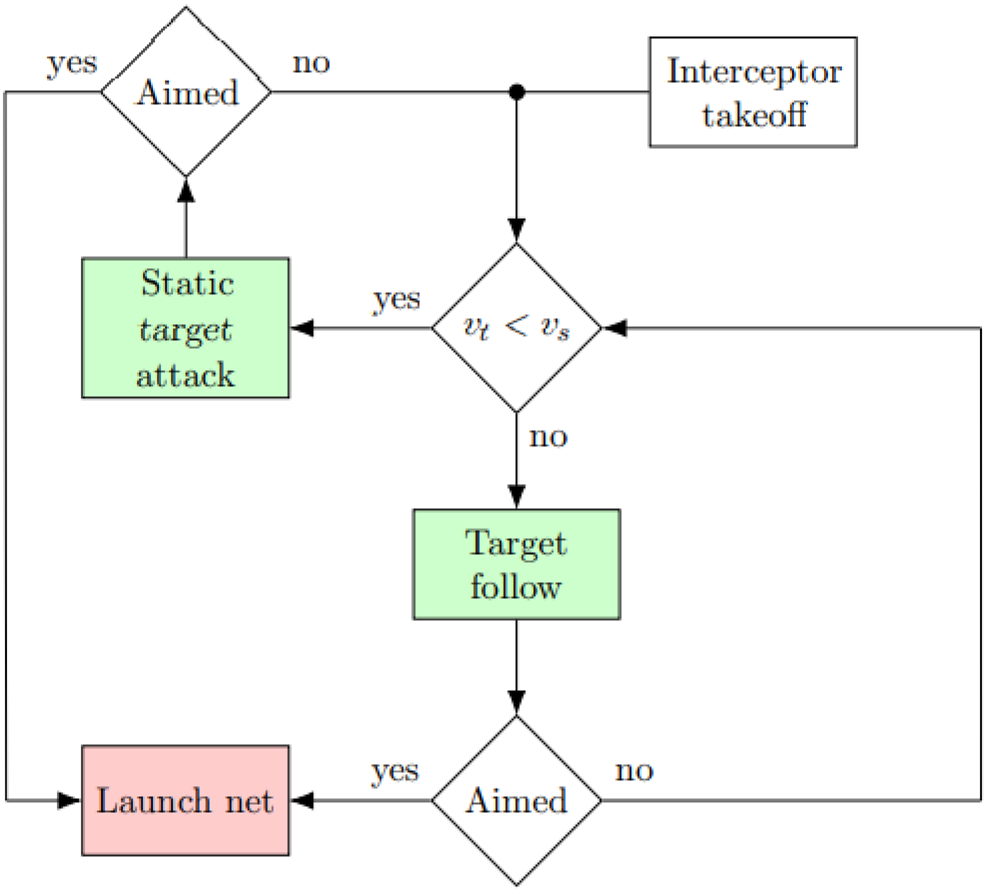


Fig.24 Kinetic Technique Loop

In case of a static target, the interceptor will assume a position at the optimal distance lnet for launching, that is closest to the current position of the interceptor. Coordinates of this position xa and ya and the yaw angle θ of the interceptor are calculated as follows: xa = xe − cos(atan2(ye − yi , xe − xi))lnet, ya = ye − sin(atan2(ye − yi , xe − xi))lnet, θ = atan2(ye − ya, xe − xa), (28) where xe and ye are the estimated position of the target and xi and yi is the current position of the interceptor. The Z coordinate is set to be either the same as the Z position of the target or offset by a constant, depending on the offset of the net launcher mounting point. The algorithm for attack with a launcher is visualized in figure 21. Decision variable vt represents the total velocity of the target. If this velocity is lower than a set threshold vs, the target is considered as stationary. The decision Aimed means that the target is inside of the effective space of the launched net. In this case, the head-on attack mode is not utilized. If the interceptor misses the target with the launched net, it can either abort the attack or switch to the kinetic attack mode.

Net launcher scenario with real UAVs

To further validate the system capabilities, the interceptor was fitted with a net launcher. The used launcher is originally intended for capturing wild animals, but its performance is suitable even for capturing drones. It is powered by a single-use, 16 g CO_2 cartridges, and it launches a 3×3 m net with an initial velocity of up to 10 m/s. The construction of the launcher is very rugged, which is not ideal for aerial use, as the mass of the loaded launcher is 1090 g.

Fig.25 Interception equipped with net launcher

As the net launcher is intended for hand-held usage, the triggering mechanism is a mechanical push-button. To activate the trigger remotely, a servo motor was fitted to the launcher on a 3D printed mount. The servo motor can push the trigger button, and it is controlled by the custom ATxmega control board. The board interfaces with the main computer, meaning that the launcher can be triggered directly from ROS. The interceptor equipped with the net launcher and the servo triggering mechanism is shown. If higher payload capacity was available, the launched net could stay attached to the interceptor, allowing it to carry the captured target away. The MRS platform itself has a mass of approximately 3 kg, and if the launcher is mounted, the mass exceeds 4 kg, which is much higher than the maximum recommended takeoff mass of 2.4 kg [1]. The interceptor is still capable of flying with a payload as high as this, but its thrust reserves are much lower, meaning that it cannot perform any aggressive maneuvers. The current draw from the battery is also substantial in this configuration. While hovering, the drone draws approximately 50 A of current, which is very close to the 60 A rated current of the used XT60 connectors. Any aggressive maneuvers would require an even higher current draw, meaning the connectors could melt, or weld together. This meant that the maximum velocities and accelerations of the interceptor had to be lowered, to prevent any damage. The used parameters are shown in table 9.

Fig.26 Target equipped with Whycon pattern

The target for this scenario was not another MRS platform, but a simple small quadcopter. This quadcopter was not equipped with any form of GNSS or Wi-Fi, which meant that it could not relay any information to the interceptor. The target drone was equipped with a WhyCon marker, which could be detected by the interceptor’s onboard camera. In this scenario, the WhyCon visual target localization system served as the only means for target localization. The target was controlled manually, as it is not capable of autonomous flight. Since the target does not possess any assistance mode, like altitude or position keeping its flight,

UAV	Parameter	Value
Interceptor	v_{hmax}	5.00 m/s
	a_{hmax}	1.5 m/s^2
	$\dot{a}_{hmax}$	2 m/s^3
	v_{vmax}	1 m/s
	a_{vmax}	1 m/s^2
	$\dot{a}_{vmax}$	2 m/s^3

'arameters for the MPC tracker of the interceptor in the net launcher scenario.

was much more erratic than that of a standard commercially available drone, like the DJI Phantom. This made the interception task harder, to test the system properly. The interceptor was positioned to an initial position at an altitude of 4.5 m and waited for the target to appear. As the WhyCon pattern was detected, the interceptor started to follow the target, and after it reached a suitable position, the net was launched, and the target was captured. The launching of the net was triggered only if three specific conditions were met at the same time, defining the effective space of the net (figure 19). The conditions were specified as follows: $T_{x1} < dist3D(x_{int}, x_{tgt}[t]) < T_{x2}$, $T_{z1} < (z_{int} - z_{tgt}[t]) - o_w < T_{z2}$, $T_{\Psi 1} < (\Psi_{int} - atan2(y_{tgt}[t] - y_{int}, x_{tgt}[t] - x_{int})) < T_{\Psi 2}$, (31) where dist3D is the three dimensional distance, xint is the current position of the interceptor (consisting of xint, yint and zint), xtgt[t] is the estimated target position at a time sample t (consisting of xtgt[t] , ytgt[t] and ztgt[t]), while the time sample t is set to correspond with the estimated system delay caused by image processing and other factors. Ψint is the interceptor's yaw angle. Variables Tx1, Tx2, Tz1, Tz2, TΨ1 and TΨ2 specify the thresholds for the conditions, and ow is the Z offset caused by camera and WhyCon pattern placement. This set of condition defines that the target has to be at a certain distance and relative altitude to the interceptor, while the interceptor's front is pointed at the target. If all three conditions are met at the same time, the net is launched. For the experiments, following .values were used: $T_{x1} = 3$ m, $T_{x2} = 5$ m, $T_{z1} = -0.3$ m, $T_{z2} = 0.3$ m, $T_{\Psi 1} = -0.06$ rad, $T_{\Psi 1} = 0.06$ rad, $o_2 = 0.7$ m. (32) Two experiments were conducted with a static target, although static, in this case, meant that the pilot was trying to keep the target in the same position, still resulting in a lot of movement. The target was captured in both cases, which is shown in figures 44 and 45. In the second case, the target was not hit in an ideal way, which was caused by wrongly estimating the delay in the system. The whole process of the camera capturing an image, relaying it to the main computer, image processing, commanding the net launcher to launch and the servo motor pushing the trigger takes approximately 350 milliseconds. During these experiments, this delay was not estimated correctly, causing the interceptor to launch the net later and almost missing the target. The same issue caused a miss in the next scenario with a moving target, which prompted a reevaluation of the estimated delay and correction of the issue.

Fig.27 Interceptor launching net and hitting the target

NON KINETIC ANTI DRONE SYSTEM

There are basically two ways in which we can destroy a drone using non kinetic technologies:

1) Jammers
2) Spoofing

What does it mean to “jam” or “spoof” a drone? What’s the difference?

Pilots use remote controls to connect with their drones and direct their flightpath, however the radio signals between the remote control and drone can be interrupted. A blanket term for this deliberate radio signal interruption is called **jamming**, but there are other ways to interfere with a pilot and their drone, including **spoofing.**

Jamming specifically refers to intentionally using a transmission blocking signal to disrupt communications between a drone and the pilot.

Once a person jams a drone, they can force the drone to do the following:

- Land on the spot, halting any further movement.
- Return to “home” location. This is a normal function of a drone with GPS and a home location feature. It is designed so that if you lose connection, your drone comes back to where it took off.

Spoofing a drone refers to a third party taking over the drone remotely, by impersonating the remote control. It involves emitting a signal that is supposed to confuse the drone, so that it thinks the spoofing signal is legitimate.

Done correctly, spoofing allows a third party to do the following:

- Take over the drone and direct the flight.
- Download data from the drone or view its camera feed.

What tools do you need to jam or spoof a drone?

The sale and use of jammers is illegal for individuals and enterprises, but they are still easily attainable online. Generally, a jammer is comprised of a transmitter, which can take different shapes and sizes. When aimed and fixed on a drone, a jammer disrupts the radio and GPS signals guiding it, and depending on the technology used, can deploy this interruption from thousands of feet away.

How do drone jammers work?

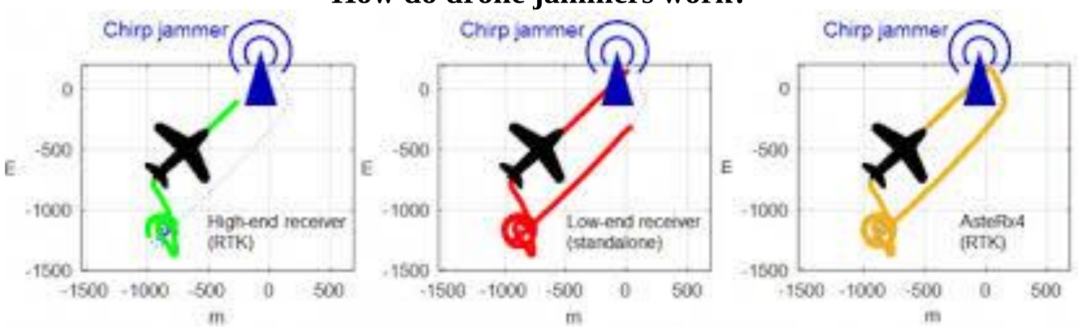


Fig.28 jammer graph

Short of shooting down a drone with physical projectiles, the only anti-drone technology in existence is what is commonly known as a “drone jammer.” As its name implies, such a device will jam the frequency – either 2.4 GHz or 5.8 GHz – that a drone uses to communicate with its ground station. The drone jammer does this by sending its own electromagnetic signal at the same frequency, thus overriding the drone’s communication systems. In most cases, this will result in the drone activating its Return to Home function, through which the drone pilot can be identified.

This description may conjure images of a drone jammer that looks like a gun, but this may not necessarily be the case. True enough, there are handheld drone jammers in existence. However, these are heavy and bulky devices that take a lot of effort to deploy and can hardly be used stealthily. More commonly used are perimeter-based drone jamming technologies that use signal emitters placed around an area that needs to be protected from drone intrusion.

What happens to a drone after it's jammed?

- The drone will land or,
- The drone will return to its home location

What are the disadvantages of drone jamming?

Jammers have five major disadvantages as C-UAS:

1. Drone jammers are illegal in most countries, including the US.
2. Drone jammers are less effective against drones that have been pre-programmed to fly a certain path, since drones can fly without GPS.
3. Drone jammers do not allow the C-UAS to achieve positive control over its targets.
4. Drone jammers do not locate the pilot or flightpath
5. Drone jammers disrupt other nearby communication signals such as cellphones and could prevent 9-1-1 calls in the event of a real attack.

What is a drone spoofer?

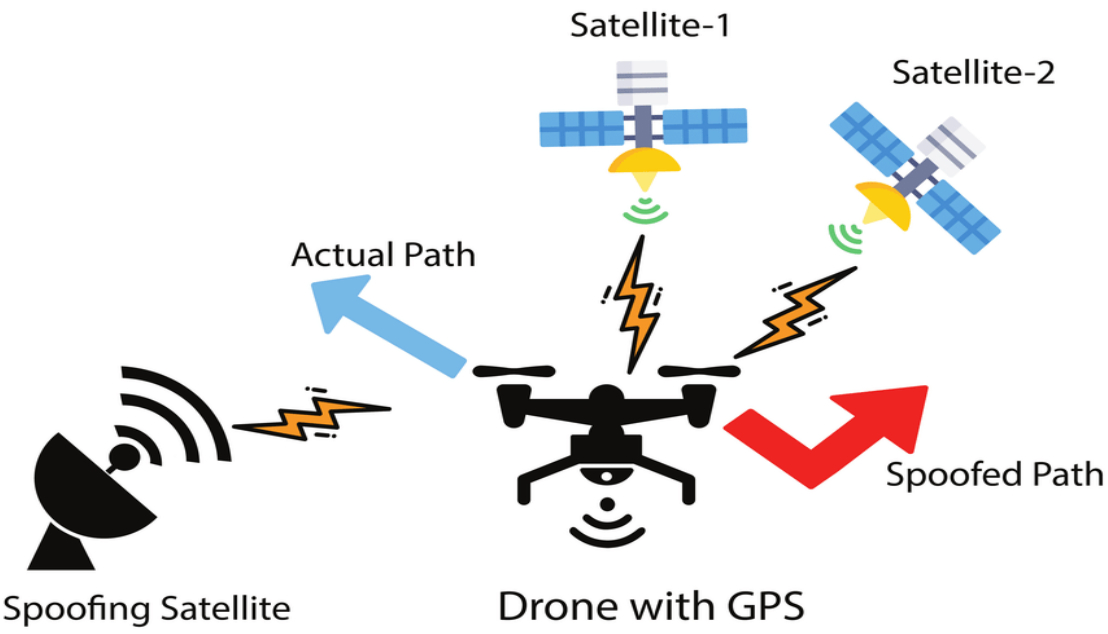


Fig.28 Drone spoofing

While jammers work by blocking RF frequencies, spoofers send fake GPS signals that mimic legitimate ones. Spoofers hijack a drone's communication link by emitting a counterfeit signal that the device reads as valid because it is a copy of the real signal.

The spoofer works by emitting a stronger counterfeit signal. The spoofer can cause a small delay between drone and controller; then, the spoofer emits the stronger false signal. The spoofer now has control over the device and can pilot the drone. The spoofer deceives the GPS receiver

GPS spoofing is hard to defend against if your UAS device is using GPS for flight. GPS is a signal broadcasted from satellites. You can't add standard protections tools such as encryption and certificates to GPS satellite signals.

What happens to a spoofed drone?

- Direct the flight; you are now the pilot
- Access any data on the drone, including the camera feed and historical flight data

Disadvantage to using a spoofer to counter a drone?

Spoofer have four major disadvantages as C-UAS:

- Drone spoofers are illegal in most countries, including the US.
- Drone spoofers are less effective against drones not using GPS.
- Drone spoofers do not locate the pilot or flightpath.
- Drone jammers disrupt other nearby GPS signals making it difficult for authorities to use GPS devices in the event of a real emergency.

Spoofer Implementation

The spoofer tracks the UAV position, velocity, and acceleration with a generalized pseudo-Bayesian estimator of the second order (GPB2), a multiple-model filter that is well-suited for tracking maneuvering targets (BarShalom et al., 2001). The GPB2 estimator assumes two modes for the UAV: (1) non-maneuvering, wherein the UAV process model is driven by white acceleration noise, and (2) maneuvering, wherein the UAV process model is driven by Wiener acceleration noise. GPS spoofing causes the UAV’s estimator to produce an erroneous estimate of accelerometer bias, an effect that can be approximately modeled as a Wiener process. The GPB2 estimator uses two models for the UAV motion that reflect the cumulative effect of maneuvering and erroneous bias estimates. These models are both driven by Wiener process accelerations, but with different intensities. The spoofer controller that produces a $\star$ is implemented as a PD compensator with chosen gain Ks = [0.01 0.1], which is within the stability region . The spoofer plant is implemented as a discrete-time double integrator on the output of the spoofer controller. It is assumed that the spoofer can produce simulated signals that result in GPS measurements at the UAV equal to the output of the spoofer plant. The processing delay within the spoofer is presumed to be zero and the 10 Hz spoofer updates are synchronized with the 10 Hz controller updates in the UAV.

ADVANTAGES AND APPLICATIONS

1. Anti drone technology is deployed to protect areas such as airports, critical infrastructure, large public spaces such as stadiums, and military installations and battlefield sites.
2. It is used by the security enforcing agencies to shoot down the rogue drones that can be a hazard to important security infrastructures.
3. Some of the advantages that are introduced due to induction of these systems is as follows:

- Anti drone systems are used to detect and/or intercept unwanted drones and unmanned aerial vehicles (UAVs). Hostile drones may be used to deploy explosives, smuggle contraband or gather intelligence on sensitive assets, and the proliferation of low-cost UAVs has led to an increase in incidents.

- Radar detection can also be used to detect UAVs. Traditional military and aviation radar systems, which are designed to pick up large aircraft, may struggle to pick up smaller drones, or to distinguish them from other objects such as birds. They may also find it difficult to deal with drones that move slowly or hover.

- Modern anti drone radar systems may use a variety of radar technologies, including ESA (electronically scanned array), staring radar, and micro-Doppler, depending on requirements for range, size of protection zone, number of simultaneous targets to track, and ability to deal with environmental clutter. They provide 3D airspace tracking and use sophisticated signal processing techniques to accurately detect and identify drones.

CONCLUSION

At the end of the day, defending a drone by just shooting at them by a rifle is not always the solution. This fact leads to the development of advanced drone neutralizing/capturing equipments such as drone guns or drone deactivators, so one can point the weapon towards the drone and bring it down.

Other techniques such as unique RADARs, Wi-Fi disablement, malicious codes or hijacking can also be used as Anti-drone systems. It looks like the field of anti-drone systems is slowly escalating, to deal with the possible security threats looming around.

Counter drone technology refers to systems that are used to detect and/or intercept unmanned aircraft systems while in flight. The technology is rapidly emerging and evolving as the mass adoption of drones takes place. Its growth can be linked to the increase in concerns about the threat that drones pose in civilian and military environments.

Many countries are investing money to develop these technologies such as the US DOD (United States Department of Defense) has earmarked about 404 million dollars for R&D and only 83 million dollars for the procurement for ground-based drones and counter drone systems. Also, it is spending about 85 million dollars to develop a counter drone system for the airborne system.

As far as India is concerned, it has developed the soft kill counter-drone system by the industry and soft and hard kill by the DRDO. The soft kill or non-kinetic measures against drone attacks include using jammers to disrupt the communication of the drones, disrupting the GPS signals or spoofing them. The kinetic or hard-kill measures include the use of bullets or guns to disrupt the mechanisms of drones.

FUTURE SCOPE

The global anti-drone market is primarily driven by the increasing concern regarding potential security threats from unauthorized aircraft systems for both civilian and military use. The special integration software in anti-drone provides simultaneous use and smooth operation of the different counter-UAV solutions. A significant rise in terrorism and illegal activities is also fueling the market growth. Besides this, anti-drones are used to track hostile drones that contain explosives to smuggle contraband and gather intelligence or sensitive assets. Furthermore, the growing adoption of UAVs for professional and leisure use has increased the concern regarding aerial attacks among the government and public, which is expected to impact the market growth in the coming years.

Landscape of the anti drone technology market with some of the key players being:

- Blighter Surveillance Systems Ltd
- Dedrone GmbH
- DeTect Inc.
- Drone Major Limited
- DroneShield Ltd
- Israel Aerospace Industries Ltd.
- Liteye Systems Inc.
- Lockheed Martin Corporation
- Saab AB
- SRC Inc.
- Thales Group
- Raytheon Technologies Corporation

Anti Drone Market Segmentation:
The market has been categorized on region, mitigation type, defense type industry and end use type.

Breakup by Mitigation Type:

- Destructive System
- Non-destructive System

Breakup by Defense Type:

- Drone Detection and Disruption Systems
- Drone Detection Systems

Breakup by End Use:

- Military and Defense
- Commercial
- Government
- Others

Breakup by Region:

- North America (United States, Canada)
- Europe (Germany, France, United Kingdom, Italy, Spain, Others)
- Asia Pacific (China, Japan, India, Australia, Indonesia, Korea, Others)
- Latin America (Brazil, Mexico, Others)
- Middle East and Africa (United Arab Emirates, Saudi Arabia, Qatar, Iraq, Other)

Countermeasures will have to adapt and evolve in step with all this advancing aerial technology. One obvious challenge is posed by the inevitable increase in autonomy. In a few short years, commercial and consumer drones will be able to operate with an even greater amount of independence than imagined today. And because technology is improving so rapidly, they may no longer rely upon GPS or radio signals to do so.

In this scenario, a flying robot with no centralized command and control presents a unique type of threat. The irony is that brute force kinetic techniques again become the most effective.

In the meantime, concerned entities are going to have to take a multi-pronged approach to drone countermeasures. This means a combination of situational awareness, real-time identification, access to centralized registration databases and the technological capability to do something with that information under pressure.

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