



DRONESHIELD

Counterdrone Factbook

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droneshield.com

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The Emerging Threat

Proliferation of Commercial Drones

The rise of drones is evident today, almost ubiquitous across industries. Today drones represent a greater than \$4.4 Billion industry, with expectations of the industry reaching \$64 Billion by 2025. Whether utilized for aerial mapping and photography, delivery services, disaster relief, performing security or agriculture operations, drone technology is being utilized in numerous positive ways. There is no doubt that drones are here to stay and will become an even more prominent fixture in the airspaces above us.

Increased Risk and Widespread Threat

The continued proliferation of drones or Unmanned Aerial Systems (UAS) provides increased opportunities for beneficial uses, but equally presents increased opportunities for bad actors to leverage these capabilities to carry out less desirable operations.

Counterdrone or Counter-UAS as an industry is still a young concept, only emerging with any sophistication in the past few years. In such a short time, just as with the UAS industry itself, the need for counterdrone capabilities has expanded to essentially every industry. Military, law enforcement, prisons might be obvious markets for counterdrone, however increased activity and threats have airports, critical infrastructure, and energy producers worldwide vulnerable as well.

Notable Drone Incidents

News involving criminal activities utilizing drones populate the headlines on a near weekly basis. These stories range from clueless and careless operators obstructing emergency operations to more sinister attackers such as the drone strikes on oil fields and attacks on government buildings and personnel. In the last few years alone, there have been highly visible incidents on a global scale. A few examples spanning both commercial and military operations include:

Gatwick Airport (2018)

- Drone activity reported within 1 km (0.62 m) of the airport
- The reports caused major disruption, affecting approximately 140,000 passengers and 1,000 flights from Dec 19-21, 2018
- Months later, April 2019, Gatwick had to close again and divert 3 flights due to an unconfirmed sighting of drone

Saudi Aramco Oil Fields (Abqaiq-Kurais Attack) (2019)

- Drone swarms were used to attack state-owned Saudi Aramco oil processing facilities at Abqaiq and Kurais in eastern Saudi Arabia
- The attacks caused both facilities to close, reducing Saudi Arabia's oil production by 50% (representing 5% of the global supply)

Attacks on U.S. Troops (2020)

- U.S. troops from the West Virginia National Guard were confronted with a multi-day attack by small UAS (sUAS) drones dropping improvised explosives above them
- The drones and attackers could not be identified, however the mortar involved sophisticated 3D printed components

Threat Categories

Drone threats can be classified by the following three tiers:

- Nuisance Activity: Negligent use, protests, or careless operation
- Intelligence Gathering: Surveillance, collecting sensitive information and imagery
- Payload delivery: Explosives, contraband, and similar packages

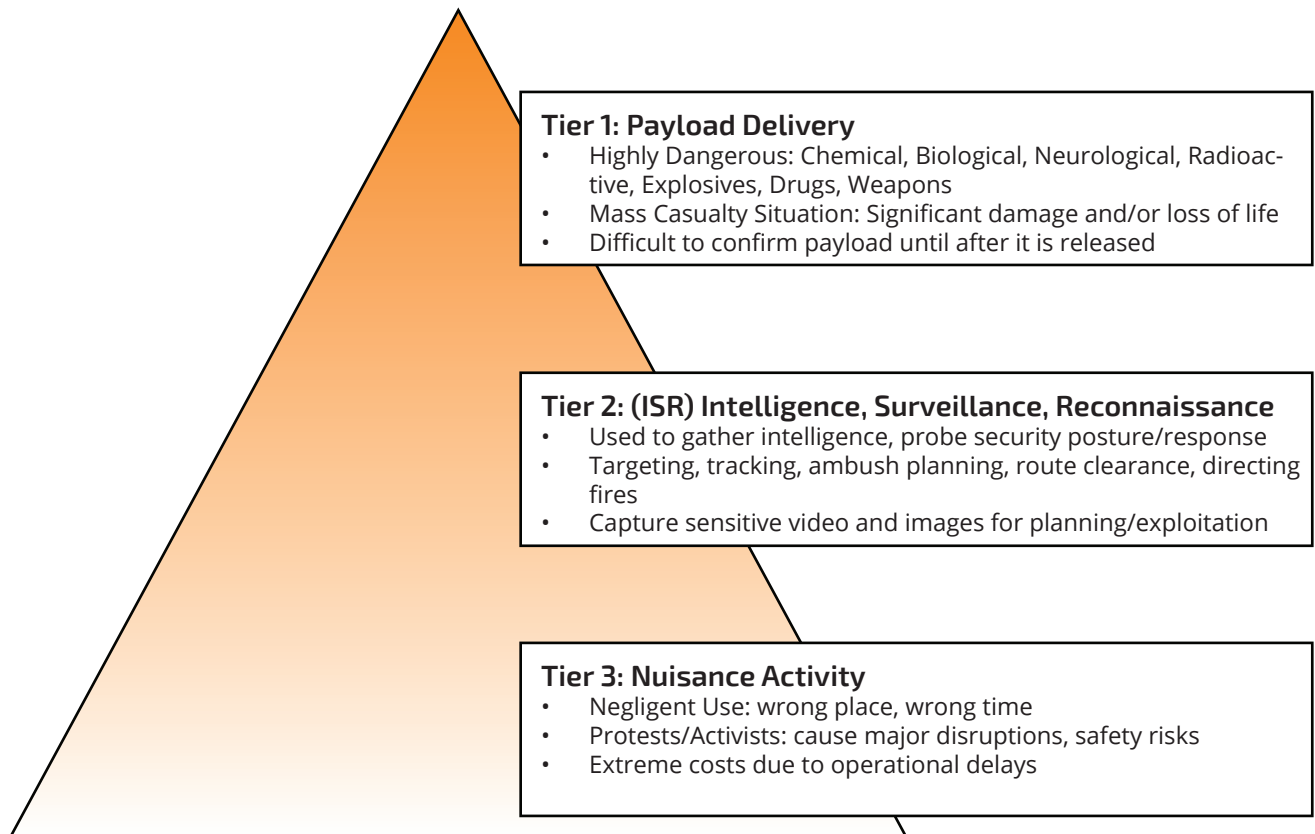


Figure 1: Threat Categories

While this guide focuses on unmanned aerial system (UAS) drones, the risk and threat are easily applicable to ground or land based and maritime unmanned autonomous vehicles (UAVs).



Figure 2: Unmanned ground and water surface vehicles (UGVs and USVs)

Underwater unmanned vehicles (UUVs) generally need different types of detection and defeat technologies due to how communication signals propagate underwater.

The threat as it relates to the drone operator typically is categorized by the 3 “C”s – Clueless, Careless and Criminal. Often it is impossible to determine whether a drone is flown by a child or a terrorist, until it is too late. In many cases, such as airport, it does not matter the operator’s intention as the mere presence of a drone in restricted airspace has the same negative effect.

Drone Types

“Airborne drones” is a broad term including everything from a \$100 off-the-shelf drone to a \$1B military platform. It’s important to distinguish between the different types of drones. The United States Department of Defense has created the following classification system for UAS.


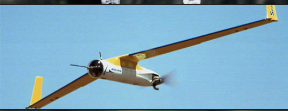

UAS Groups	Maximum Weight (lbs) (MGTOV)	Normal Operating Altitude (ft)	Speed (kts)	Representative UAS	
Group 1	0-20	<1200 AGL	<100	Consumer and Commercial UAS, Raven (RQ-11), WASP	
Group 2	21-55	<3500 AGL	<250	ScanEagle	
Group 3	<1300	<FL 180		Shadow (RQ-78), Tier II/STUAS	
Group 4	>1320			Any Airspeed	Fire Scout (MQ-88, RQ-88), Predator (MQ-1A/B), Sky Warrior ERMP (MQ-1C)
Group 5			>FL 180		Reaper (MQ-9A), Global Hawk (RQ-4), BAMS (RQ-4N)

Figure 3: DoD UAS Group Descriptions

The main difference between the Groups is size – higher groups are larger, heavier, and offer greater payload capabilities. Higher groups typically require or leverage higher flight altitude reach, maximum speed and flight time. Non-State actors will generally only have access to Group 1 and 2 drones, such as DJI Phantoms and other commercially available drones. It is those two Groups that drive the rise of asymmetric warfare, where drones are turned into cheap, easily accessible weapons and platforms for criminal activity. This handbook focuses on these two Groups of drones.

Smaller drone classes are typically categorized as one of the following common drone types:



Multi-copters		<ul style="list-style-type: none"> • Examples: DJI Phantom, Yuneec Typhoon, Parrot Bebop • Vertical take-off and landing, hovering ability • Shorter flight distances compared to fixed wing • Easy to fly
Fixed Wing		<ul style="list-style-type: none"> • Examples: Parrot Disco, Skywalker X8, E-flite Opterra • Longer range, higher speed • Cannot hover, harder to fly compared to multi-copter

Figure 4: Drone Types

Other types include Vertical Take-off and Landing, or VTOL, a hybrid of the multi-copter and fixed-wing, and tethered drones, blimps, and kites. Terrorists have been known to pair kites with burning fuel or explosives and have them drift downwind toward targets i.e. “Kite Wars”.

The Role of Counterdrone Solutions

Counterdrone solutions typically offer one or a combination of the following capabilities; Detect, Identify, Track, and Defeat. The simplest way to classify counterdrone is the ability to “Detect and Respond”.

The first step towards drone protection is knowing when the threat appears, where it is located or in the event of a swarm of drones, where the multiple threats are located, and ideally where the source (or pilot) is located. While tracking the drone in real-time, an appropriate response can be taken based on its location – eg apprehend the drone pilot.

Identification of a drone, sometimes referred to as classification, is also important. Even with Group 1 drones, there is a considerable range – from under 100g or less (with very short flight times and negligible payload capability) to drones such as the DJI Matrice 600, which can carry over 6 kg. Identification of whether the drone is carrying a camera and/or additional payload is also relevant and can help assess the threat. Examples of some of the larger Group 1 drones are depicted in the figure below. Although originally designed for agricultural use or large camera payloads,, these drones can and have been easily adapted to carry out terrorist attacks and other criminal acts:





			
DJI Agras MG-1	Freely Alta-8	DJI S1000	DJI Matrice 600
10km payload	9kg payload	6.8kg payload	6kg payload
1km range	2km range	2km range	5km range
24min flight time	16min flight time	15min flight time	16min flight time

Figure 5: Examples of heavy lifting small drones

Detection Methods

Radio Frequency (RF)

An RF detection sensor is the base layer of any effective counterdrone system. RF sensors provide detection capability by matching drone communication protocols to known drone RF signatures. Commercial and consumer grade drones use a variety of protocols, some of which are proprietary. RF-based detection systems that simply scan the frequency bands commonly used by drones, for example, those that use Wi-Fi scanners or “sniffers”, run the risk of producing extremely high rates of false alarms.

RF sensors typically are “passive” in nature and do not broadcast or transmit. This allows RF counterdrone systems to operate without causing any interference for other communications on the network or in the operational area. The exception to the passive RF systems are those that actively use protocol manipulation or attempt to “hack” drones.

In addition to the passive advantage of RF systems, other desirable features typically exist for using RF counterdrone systems. Critical features will be dependent on the operational scenario and environment, but here are some factors to consider when evaluating RF solutions:

- A large, upgradeable RF signature library or detection engine to provide high probability of detection and low false alarm ratios
- Ability to tag or filter false alarms to optimize and improve performance over time
- Azimuth and vertical coverage angles optimized for drone or UAS detection
- RF direction-finding (DF) capability of drone and controller

RF sensors typically provide much further detection range than radar systems, when considering the cost of each. The ability to DF based on RF can also provide tracking capability similar to that of radar systems.

RF can be an adaptable technology for drone detection as evidenced by innovative solutions, such as body-worn, handheld, and vehicle-based products providing counterdrone capability in challenging field environments and during “on-the-move” operations.



Figure 6: DroneShield's RfOne™ sensor

As with all methods, there are some challenges with RF that any effective system will need to overcome. Multipath is present in most real-world environments and can significantly reduce the accuracy of an RF system. This is where the system receives a signal from multiple directions simultaneously due to signal reflection. Any effective system should be able to determine the bearing of the drone with a high degree of accuracy, despite the presence of multipath.

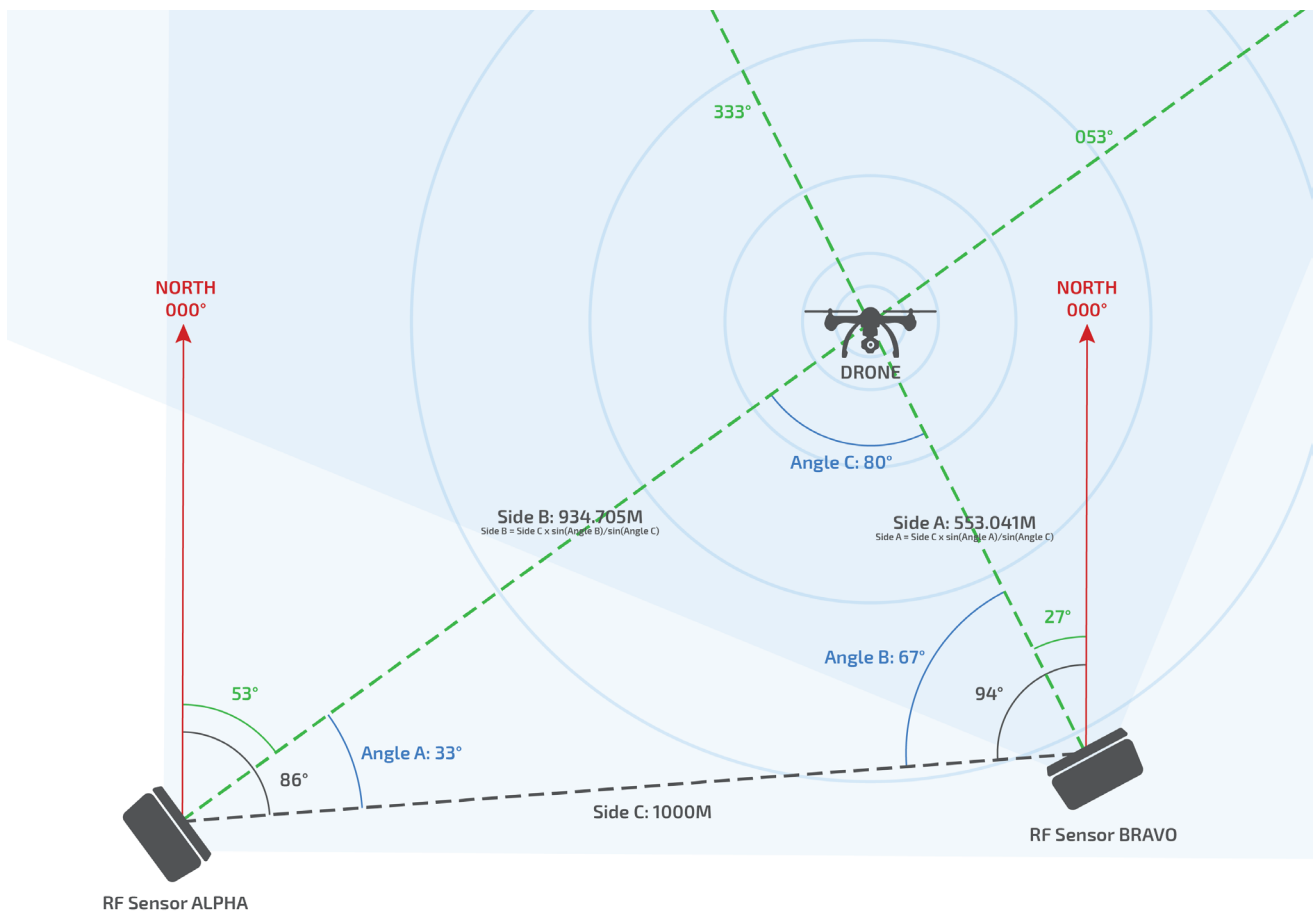


Figure 7: RF triangulation of a drone location

With the coming advent of LTE controlled drones, RF sensor technology must continue to evolve.

Another common question is performance of the RF sensors for “autonomous” drones. While many so-called autonomous drones still emit telemetry and video data, making it detectable to the RF sensor, such drones with an SD card (or similar) and utilising camera navigation or Inertial Navigation System (INS) can be much more invisible, thus requiring reliance on other sensors to RF.

There are essentially 5 categories of drone RF communications globally:

- Remote Control (RC) hobbyist drones, licenced for control in traditional shared hobbyist frequency bands. These bands are not designated for use outside of low baud rate telemetry control
- ISM (Industrial Scientific and Industrial) band hobbyist drones which are essentially licence free but regulated in terms of applications, output power and spectral purity
- Commercial drones, operational as compliant within allocated bands by the respective country's civil regulator
- Defence and military drones, not regulated by civil regulators, who use traditional military communication bands, details of which are normally classified

Any RF-controlled drones operational outside of the first three categories are considered as illegal and intent to operate them is in contravention to the respective countries governing radio communication laws.

There is already a proliferation of bolt-on third party transceivers, modems and up/down convertors being offered in certain identified countries that could be imported and used illegally, and competent counterdrone manufacturers keep up to date with these developments as they arise.

Counterdrone technology capabilities and innovation are growing exponentially, offering effective drone and remote controller detection and countermeasure products to meet and challenge sophisticated drone technologies where necessary.

Radar

A radar is effectively a motion tracker and has many other applications than drone tracking. For counterdrone applications, the key is to use a radar that has sufficiently fine resolution to detect small drones such as DJI Phantoms and smaller, at meaningful distances which is typically 1 km or greater. Numerous radars, such as low frequency pulse radar, have been designed to detect large metal objects like planes and helicopters, but are less suited for detecting small radar cross section, carbon body objects that fly lower to the ground, as Group 1 and 2 drones fly.

Other considerations when evaluating counterdrone radar options include:

Dealing with ground clutter: Ground clutter can interfere with detection and generate false alarms from objects like trees and ventilation fans on buildings roofs, as these appears much like drone blades to a radar. Advanced radar systems will apply various techniques to minimize this effect.

Azimuth coverage: Azimuth is the horizontal coverage angle for radar. Typical ranges for a system are from 90 degrees to 360 degrees. For less than 360-degrees, multiple radars can be used to deliver a wider angle and overall coverage area.

Vertical angle: Vertical angle of a radar tends to get overlooked. A lot of radars on the market have narrow vertical angle, between 10-30 degrees, leading to potentially significant blind spots in vertical coverage. While a 90-degree vertical coverage is not usually needed, 40-80 degree detection is considered desirable.

2D vs 3D: 3D radar has several advantages over 2D, most notably, it provides elevation data on the drone. Also, the ability to reduce clutter by filtering objects past certain heights aids in eliminating ground based false alarms.

Frequency Bands: Counterdrone radar bands include X-band (also commonly used on boats), K-band (originally used for self-driving cars, but adapted for counterdrone), Ku-band and S-band (common with military deployments). The band used also influences the size of the radar, as an example, K-band radars typically come in smaller form factors.

Moving vs fixed panel: Depending on the use case, less moving parts may be preferable, as this reduces wear and tear and the potential for damage. Some radars can be used in both “staring”

and spinning mode, with staring mode providing better performance, but a reduced coverage angle.

Radar Transmission Modes

Drone detection radars can utilize different technical approaches. Radars used in counterdrone solutions use one of the following three techniques; Pulse (active), Continuous Wave (active), and Passive mode. Each approach has different characteristics that might have advantages or disadvantages during operations depending on the requirements.

Active Radar - Pulse: Transmits a very short, but high-power pulse and waits for the reflected echo from the target. The performance is influenced by the duration of the transmitted pulses and the echo receiving time window. The shorter pulse duration results in a higher range resolution. Consequently, pulse radars are generally designed for long distances.

Active Radar - Continuous Wave: These radars continuously transmit an illumination signal and simultaneously receives echo reflections. A moving object's speed and trajectory can be determined by observing its frequency shift, as seen at the receiver, due to the Doppler effect. Continuous wave systems are not able to perform range measurements without including a timing reference in the transmitted signal.

Passive Radar: Makes use of existing environmental broadcast, communication or radio-navigation transmission signals to detect the presence of objects in the receiver monitoring area. The system transmitter and receiver are at separate locations and the user only has control of the receivers. Potential illumination signals that could be used for drone detection include FM, DVB, GSM, GNSS or WIFI. This approach is attractive for operations where end users prefer to use non-emitting devices so not to produce a noticeable signature during operations.

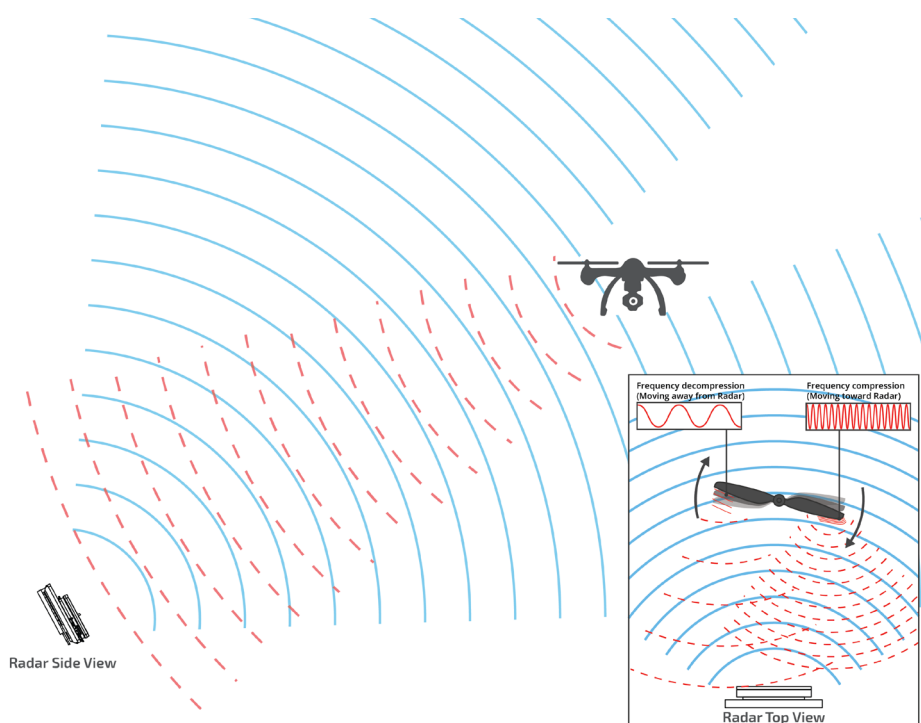


Figure 8: Micro-Doppler radar detecting a drone

Current Radar Developments

Radar manufacturers have been leveraging technologies like micro-Doppler and Artificial Intelligence to more accurately differentiate between drones and other similar sized objects. As a potential technology obstacle, the micro-Doppler effect is expected to reduce significantly once drone rotor blades are required by law to be covered by a protective cage (an expected safety development, given reported incidents of drone blades causing body and eye injuries by drone blades on contact).

Compliance

Compliance is an important part of purchasing a radar, as it is an active emitter. FCC is overseeing certifications of radars in the US, OFCOM in UK, ACMA in Australia, and similar organisations elsewhere globally.

Acoustic

There are two primary types of acoustic hardware used for drone detection today – arrays and single-microphones. Arrays have the advantage of determining more precise location of the source; however, they are significantly more expensive with a larger form-factor than single microphone hardware.

Acoustic detection software works by removing the background clutter from noise made by the drone blades and/or motor and comparing it to the database of acoustic signatures. Like early RF detection, multiple drones map to “signatures” and a signature library and regular updates are needed to remain accurate and effective. It is worth noting that some of the more recent drones are significantly quieter compared to earlier generations of drones, making the job of acoustic sensors more challenging.



Figure 9: DroneShield FarAlert™ sensor installation

Acoustic sensor technology is expected to respond well to AI, however to date it has not been incorporated in a meaningful way.

Advancing are currently being made in acoustic detection, which can make them a viable complementary option or layer for counterdrone operations, however overall drone detection capabilities based on acoustics still provide inferior standalone performance when compared to other methods such as radar or RF sensors.

Optics

Electro-Optical (EO) and Infrared (IR) camera detection are popular components, often paired with other sensors, to produce integrated or multi-sensor counterdrone solutions.

Performance trade-offs between field of view (FOV) and distance need to be considered when using EO or EO/IR cameras. The greater the angle that is being monitored, the less the distance. Even expensive, high-quality cameras, with a 90-degree view, will struggle to detect a drone much further than a few hundred meters without being initially cued by another sensor such as radar or RF.

Optical detection is another method that has benefitted from recent advances in AI and computer vision. Even within the last 12 months, new techniques have emerged allowing very high precision detection and classification algorithms for drones to be developed.



Figure 10: DroneShield's DroneOptID™ software detecting and classifying multiple white drones against a white arctic backdrop. Red overlay represents pixels identified as 'drone object' tracked by the software

In a multi-sensor system, cameras can serve in a slew-to-cue function based on the detection provided by the primary sensors. The camera is directed toward the detection of known drone activity and then can zoom on target and track. At this point, video analytics can provide further identification or capture image and video of the drone activity as evidence of the drone intrusion. More advanced analytics are useful for potentially identifying the drone's payload and performing other autonomous threat assessment tasks.

Multi-sensor Systems

The main drone detection methods today include RF, radar, and acoustic sensors, as well as optical and thermal sensors for further confirmation. A multi-sensor system will incorporate several or all of these into an integrated solution, providing multiple "layers" of detection. These layers can provide a more effective solution against diverse drone threats as combining sensors often mitigates potential capabilities gaps of any single method. The inclusion of multiple sensors makes for a more comprehensive and complex system, however, can lead to a higher

cost solution when compared to single method solutions.



Figure 11: DroneShield's DroneSentinel™ multi-sensor system

More exotic detection sensors exist for counterdrone, such as light detection and ranging or LIDAR, however these have limited application and have not been widely adopted or effective to date.

It is important to understand that there is no "one-size-fits-all" for counterdrone solutions and the role of the counterdrone manufacturers and providers is to keep up with the constantly evolving commercial drone technology and evolve with it.

Defeat Methods

Defeat and mitigation solutions available in the counterdrone space today include both "soft-kill" and "hard-kill" solutions. Soft-kill solutions involve methods that do not intentionally damage the drone physically. Soft methods might include frequency jamming technology or drone "hacking." Hard-kill solutions involve physical methods that have the potential to hit the drone with another object or projectile. These types of solutions can range from drone seeking drones to kinetic solutions such as lasers and ammunition.

Soft-kill solutions typically carry less risk of collateral damage due to their non-kinetic nature and are more subtle and discreet when operating. As a result, hard-kill and kinetic methods are reserved for government use, and almost exclusively for military and federal-level use, with few exceptions. Although more widely used, even non-kinetic methods encounter varying levels of authority to operate, even among government agencies.

RF Jamming Technology

RF jammers operate by transmitting on the same frequency a drone uses to communicate with the controller or operator. When the jamming signal is "stronger" at the drone than the signal of the controller to the drone, the drone loses its connection forcing it to go into a pre-set emergency protocol causing the drone to fly back to its starting point, hover, or land.

Group 1 and 2 drones communicate within known, unallocated frequency bands such as 2.4 GHz and 5.8 GHz. These frequencies are used for both communication between drone and controller and also video for first-person view or FPV. Drone manufacturers are required to remain within the unallocated spectrum. Other less common RF frequency bands that are commercially used include the 433 MHz and 915 MHz ISM bands.

Jammers come in both direction and omni-directional (360-degree) solutions. Omni-directional may provide more defeat coverage, however directional or sector-based solutions can provide more precision coverage and mitigate unintended interference.



Figure 12: French Army deploying DroneShield DroneGun Tactical™ drone jammer

Global Navigation Satellite System (GNSS) Jamming

GPS may be the most common and known navigation system, however there are other popular Global Navigation Satellite Systems used worldwide, such as GLONASS (Russian), Galileo (European), and Beidou (Chinese) systems. Commercial and consumer drones frequently come with multiple GNSS capability.

If jamming a drone's RF frequency, it may still utilize GNSS to fly back to its point of origin or continue along a pre-programmed navigation path. By jamming both the RF and GNSS the drone is severed from its communication and navigation link and is unable to fly home or continue its pre-programmed flight path. Based on the capability of the drone, it may attempt to land once jammed or it may just hover in place where first engaged by the jammer.

Spoofing

Spoofing or “hacking” involves a form of protocol manipulation. This method includes mimicking the controller and gaining control of the drone, while acting as the controller. This defeat method when successful, allows for the system to direct or reroute the drone which can be beneficial especially for certain use cases. Spoofing can also include spoofing the GNSS signal, effectively misguiding the direction of the drone.

One limitation with this approach is that the same or similar spoofing techniques are not effective against all drones, so there is always a risk of having a “hole” in the defense. Even

effective techniques are susceptible to any software changes made by the drone manufacturer or sophisticated drone operators.

Directed Energy

Directed energy counterdrone methods include laser and high-power microwave systems. These methods are becoming more frequent, although still not common, for the threat posed by Group 1 and 2 drones. Use of directed energy for counterdrone is still in its infancy and currently being developed and evaluated for military applications.



Figure 13: Directed energy weapons

Counterdrone Drones

Kamikaze drones and drone seeking drones demonstrate various approaches to defeat. Kamikaze drones have limited commercial use as they essentially disable rogue drones by physically damaging the drone and knocking it out of the sky. Other drone seeking drones aim to catch or disable drones with projectiles such as nets or modified rounds.



Figure 14: Kamikaze drone

Using drones to catch or defeat drones struggles to scale and can be rendered defenseless against multiple or a swarm of drones, whereas the Kamikaze approach has this problem along with a high risk for collateral damage or injury.



Figure 15: Hunter drone

Other Kinetic Solutions

The maturation of other counterdrone defeat capabilities have become more desirable options than early kinetic ones such as ballistics and bursting rounds. The accuracy, efficiency, and minimal collateral damage of precision jamming provides a safer and more economic approach to defeating drones, whereas the emergence of next generation weapons such as laser systems looks to provide the same in areas of more extreme drone threats as on the battlefield.



Figure 16: Counterdrone Remote Weapon Station (RWS)

There is still a place for the traditional kinetic solutions in counterdrone and they are best positioned as part of a layered approach for military use.

Layered Defeat

Much like counterdrone detection methods, when possible, a layered approach provides more capability. Layered approaches can include both soft-kill and hard-kill options or multiple approaches so the user can employ the ideal countermeasure based on changes within the operational environment or objective.

Layered defeat solutions may not be feasible for the cost-conscience or commercial organization as many methods involve cost-prohibited or restricted technologies.

Counterdrone Providers

With counterdrone technologies rapidly coming to market to address the quickly growing drone threat, it becomes increasingly difficult for the prospective users of the technology to identify cost-effective and high-performance solutions for their specific needs.

Typically, there are three types of solution providers:

Startups and Project Companies

Counterdrone is a growing industry now, with numerous startup companies entering every year. The origins of counterdrone startups vary, but many times are a result of development projects or licensing specific technology or intellectual property and building a product around it. Innovation coming from startups can be encouraging, however stability of a startup company should also be a point of focus. Commercial drone technology is advancing at a rapid pace. As important as a company's capability today is their engineering team's vision and technical ability to scale, maintain their solutions, and advance the capability along with the fast moving commercial and after-market sectors. Many companies in this space have not yet acquired the necessary team expertise or resources to execute in one or more of these areas.

Startups and project companies can possibly offer users beneficial options, such as cost-effective products and an innovative approach to the problem. Considerations and potential trade-offs come with the company's ability to maintain relevance and performance against constantly evolving commercial developments, as well as overall quality, sustainability, and on-going support for purchased products.

Prime Contractors

Prime Defense Contractors and large System Integrators typically can offer significant capabilities in the Counterdrone market. In the past few years, leveraging their access or previous development of high-end solutions for different scenarios, such as mortar detecting radars and IED jammers, large Primes have repurposed some of these technologies for their new Counter-UAS offerings. Prime solutions also utilize existing products such as Radars or RF sensors from third-party companies that have specialized expertise in their respective fields to provide a larger "system of systems" or more complete layered solution.

A key consideration is the typically higher price of a prime solutions, which makes most of the solutions only feasible for the military. Also, repurposing or "Multi-use" technology such often

come with trade-offs or gaps in capability when compared to a technology built specifically for the nuances of drone operations. Timelines and restrictions are other factors as these technologies often result from multi-year development programs funded by the customer, and therefore can be subject to restrictions for export or commercial use.

Established Small Businesses

In the middle are companies that have survived their startup growing pains, have industry expertise in a relevant area, and can offer the agility of a dynamic team. At this stage, these companies should have evolved from a single-product company and have proven ability to scale production to meet the demand of larger customers. They typically have a funding base and or source of revenue that provides stability for their on-going development and support for their customers.

Counterdrone is not a one-size-fits-all solution, therefore, it's beneficial to seek a company that is committed to continued development and has demonstrated success with rapid product development to address evolving commercial technologies. Capable companies in this space should offer that desired balance of counterdrone focus and agility, which are both needed to field superior solutions.

Growth looks different for every company, therefore, established small businesses present various levels of product maturity, quality control, customer support, and most importantly, in-house counterdrone development expertise. Things to consider when evaluating counterdrone providers; their engineering team and capability, more than a single product or solution, vision and evidence of future product development. The company's ability to scale production, support deployed solutions, and meet customers' unique requirements are also musts for a successful solution and the success of your counterdrone operations.

What Next?

There are many considerations to make when evaluating counterdrone options. Identifying the right solution for your organization requires a clear understanding of your objectives, due diligence, and the right solution provider. Aside from the technical aspects, other considerations that may influence your decision can include;

- Overall costs of operation
- Current regulations and restrictions
- Operational area and environment
- Standard Operating Procedures for the organization

For more information on how to implement the best solution for your organization or any other counterdrone related questions, please contact us at: info@droneshield.com