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Low Cost Drones in Modern Warfare and Counter Drone Strategies - A Review

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Abstract: This review article discusses low-cost military drones, the components necessary to manufacture such a drone, its overall cost, and the threats posed by them against civilian and military targets. It considers available counter-drone technologies, examining their challenges and costs. While conventional air defense systems defend against single targets very well, defending against drone swarms will overwhelm any single missile defense solution. They are often stationary and fixed in place for easy targeting and destruction. Low-cost interceptor drones might be the answer to this dilemma. Kinetic-kill approaches seem to be the best solution, considering how inefficient jamming and cyber-attacks are and how ridiculously expensive interceptor missiles are. This paper discusses the components needed to develop interceptor drones, the deployment processes, and the strategic shift that must be made to embrace low-cost counter-drone technologies for the battlespaces of tomorrow.
Keywords: UAVs, USVs, UUVs

I. INTRODUCTION

Low-cost drones are now a revolutionary power in contemporary warfare, with unprecedented capabilities in target acquisition, surveillance, and precision strikes. Their ease of deployment, affordability, and versatility make them appealing weapons for state as well as non-state actors. Wars in the Ukraine, the Middle East, and Africa have brought out the ways in which off-the-shelf commercial drones can be repurposed to serve military purposes, facilitating asymmetric warfare and problematic for traditional defense systems. As these drones increase their operational significance, so does the necessity of creating viable counter-drone measures. Defense against such attacks must involve a multi-layered system that encompasses radar detection, electronic jamming, AI-driven tracking, and kinetic or directed-energy neutralization techniques. This review delves into the progression, uses, and implications of low-cost dronesin modern combat environments andcritically analyzes existing and developing countermeasures. Recognizing this d ynamic threat environment is crucial for creatineffective defense planning and sustaining strategic advantage in future warfare.

II. CLASSIFICATION OF LOW-COST DRONES IN MODERN WARFARE

A. Unmanned Aerial Vehicles (UAVs):

Small drones that are piloted in real time, using a first-person view (FPV) camera normally used for racing or tactical surveillance, known as FPV drones. Essentially single-use UAVs used to crash into targets and detonate, acting as flying missile known as kamikaze drones. Multiple UAVs operating together using AI coordination for attacks known as swarm drones. A swarm may consist of FPV or kamikaze drones.

B. Unmanned Surface Vehicles (USVs):

Watercraft for remote or autonomous control of surveillance, attack, or minesweeping.
Examples: Sea Baby, Magura V5.

C. Unmanned Underwater Vehicle (UUV):

submersible drone for underwater exploration, surveillance, or military operations.
Example: TLK-150.

III. COMPONENTS OF EACH DRONE TYPE

A. *Unmanned Aerial Vehicles (UAVs):*

1) FPV Drones (e.g., Queen Hornet) : Main Components [1]: Frame (5–8 inch), 4 Motors, 4 Propellers, 4-in-1 ESC, Flight Controller, LiPo Battery, FPV Video Transmitter (vTx) and Receiver (vRx), FPV Camera, Radio Control Transmitter (Tx) and Receiver (Rx), Antennas, Battery Straps.
   Optional items: Action Camera (filming), FPV Goggles, Tools
2) Kamikaze Drones (e.g., Shahed Series):_Main Components [2]: Airframe (custom made for loitering and impact), Motor(s), Propeller(s), Flight Controller, GPS Module, Battery or Fuel Cell, Warhead/Explosive Payload, Navigation and Anti-jamming Electronics (up to 140+ electronic components in Shahed-136), Communication Modules.

B. *Unmanned Surface Vehicles (USVs) (e.g., Sea Baby, Magura V5)*

Key Components [3]: Hull or Frame, Propulsion System (electric or fuel), Navigation System (GPS, IMU), Remote Control System, Communication System, Sensors (cameras, radar, sonar), Battery or Engine, Payload Bay (to carry explosives or equipment).
Unmanned Underwater Vehicle (UUV) (e.g., TLK-150) :
Key Components [4]: Pressure-Resistant Hull, Electric Propulsion, Navigation and Guidance System, Sonar and Sensors , Battery Pack, Communication Buoy/Module, Payload Bay.

C. *COST OF EACH DRONE TYPE:*

Unmanned Aerial Vehicle (UAV):
FPV Drone Queen Hornet: $1,200 [5]
Swarm Drone Generic \/ Light Show: $350–$1,000
Kamikaze DroneIndian Indigenous$500, Shahed-136 $20,000 – $50,000 (estimated) [6]
Unmanned Surface Vehicle (USV): Sea Baby, Magura V5 $250,000–500,000 (est.).
Unmanned Underwater Vehicle (UUV): TLK-150 $50,000 - $200,000 (est.).

IV. THREATS POSED BY LOW-COST DRONES AGAINST MILITARY AND CIVILIAN TARGETS

Drones are now recognized as a major threat in contemporary theatre of war owing to the following: multirole, ease in procurement, and freedom of maneuver. They inevitably present in surveillance and reconnaissance are the dangers. Another key threat is the precision they could achieve. Weapons-equipped drones can make surgical strikes on costly targets without putting human pilots in danger. This allows limited overt operations with more attacks more often and farther away without using the traditional air force. Their stealthiness and precision makes them hard to counter, particularly when they come as a shock attack. The most disquieting development in the world of drone warfare is the emergence of the swarm. Cheap drones used in mass numbers can swamp traditional air defenses. These swarms are capable of overwhelming radar systems, depleting missile stocks, and mounting massed kamikaze-style attacks on military targets. The volume and velocity of those attacks can overwhelm even the most sophisticated defense installations. Drones have also become a favored weapon in terrorist groups and insurgents' arsenals. Commercially available they can be adapted to take explosives or chemical agents. Small and with a low radar profile, they seem perfect for surprise attacks on urban or outland targets. The democratization of air power is an enormous threat against all military and civilian targets.

In the world of electronic warfare, drones can be rigged to jam communications, mess with GPS signals or, in some cases, infiltrate enemy cyber networks. Such capabilities serve to the loss of critical systems and data compromise with resulting devastating impact on operational security and command effectiveness.

And finally, drones can be deployed to sabotage vital national infrastructure. Attacking oil refineries, power plants, transportation centers, or water treatment facilities are all ways that adversaries could cause widespread dysfunction, material economic harm, and fear among the civilian population. The ability to strike from a distance and with precision makes drones a potent tool for strategic sabotage.

V. CURRENT COUNTER DRONE TECHNOLOGIES AND THEIR LIMITATIONS:

1) Jamming Systems: These systems interfere with a drone's GPS or communication link with the operator, thereby negating the ability for remote functioning of any drone.

Examples of such systems include the Israeli Drone Dome as well as the U.S. Sky Dome. However, there are caveats here. Do such systems remain useless if drones are in fact capable of autonomous operation away from any GPS or operator input? Such systems will also collide into the radio equipment in use by friendly forces.

2) Radar & RF Detection Systems: Radar and RF detection systems identify a drone by picking up on the frequencies it emits or by recognizing its radar signature. Among such systems one can find Dedrone and Hensoldt Xpeller. These systems, however, carry some limitations. Signals or patterns of movement of the drone can be quite similar to those of birds and other flying objects, thus harder to classify. Additionally, low-flying or tiny drones get under the detection scope due to their barely measurable radar or RF footprint.
3) Kinetic Systems (Missiles, Guns, Nets): Kinetic weapon systems destroy or neutralize drones, either destroying them or capturing them midair, including systems such as C-RAMs and a DroneCatcher net gun. These may be effective but have some drawbacks: when trying to shoot down very cheap and low-cost drones, they can be disproportionately expensive. In addition, these systems may be used in urban places where collateral damage to people or property may be an unacceptable risk.
4) Lasers/Microwaves (Directed Energy Weapons): Directed energy weapons, whether lasers or microwaves, disable or neutralize drones by focusing an intense energy beam to strike or damage the electronics of a drone or the drone itself while the drone is in flight. The ATHENA system of Lockheed Martin and the High Energy Laser Weapon System, or HELWS, of Raytheon are among the major examples. That's where the limitations come in: its efficiency is highly reliant on weather conditions-fog, rain, or dust may drastically decrease its effectiveness. Also, they typically are limited to power levels that constrain their range or geographic impact against distant or fast-moving targets.
5) Cyber Takeover Systems: Cyber takeover systems work by abusing flaws in a drone's software to access its control systems, therefore enabling operators to either seize the drone or force it to land. The Battelle Drone Defender is one example ofsucha system being studied. These systems, however, have major drawbacks. Usually only successful against particular drone models or software platforms, compatibility is constrained. Furthermore very challenging to attack using cyber techniques are drones using powerful encryption or working without relying on external control signals.
6) Trained Birds of Prey: Small drones are physically intercepted and caught mid-flight by trained birds of prey including eagles or falcons. Countries like France and the Netherlands have used this approach experimentally. It has some serious constraints, however. Animal use in such activities generates moral problems and may be regarded as morally dubious. Furthermore unsuited for bigger or quicker UAVs, this method is only successful against little, light drones.

VI. PAGE STYLE COST ANALYSIS OF COUNTER-DRONE TECHNOLOGIES: COMPARING SYSTEM COSTS & PER KILL EXPENSES

DRONES AGAINST MILITARY ASSETS :

Low-cost kamikaze drones can destroy air defense systems and other high-value military assets. The Armenian S-300 system was destroyed by Israeli kamikaze drones during the recent Nagorno-Karabakh war, and Ukrainian unmanned surface vehicles (USVs) have been destroying Russian naval assets.

THE CASE FOR INTERCEPTOR DRONES: REQUIREMENTS AND CHALLENGES:

Air defense is now in essence being put on trial by the vertiginous spread of drone technology. Such systems, typically derived from fixed and centralized launcher structures, can accept only a limited number of intercept targets at any one time. Traditional air defenses are likely to be overrun as drone swarms, including dozens or hundreds of cheap, disposable UAVs attacking in coordinated patterns, become more prevalent. Now, missile systems have been becoming ever more dense, which increases their vulnerability, since they are potentially easier to spot, and subsequently to quickly target, track and detected and targeted by adversaries.

SYSTEM	SYSTEM COST (USD)	COST PER KILL(USD)	DRONE COST (USD)
Jamming Systems	$ 30000- $ 500000	$ 100 - $ 1000 [Can not counter fiber-optic drones]	Fiber Optic drone [$ 350-$500] Queen Hornet [$1000]

Kinetic System (Example-FS LIDS)	$100 million [7]	$ 100000	Shahed 136 [est. $50000]
DEW (Example-Dragon Fire)	$115 MILLION [8]	$10 [LOW COST but performance is affected by weather]	Sky Striker [$ 137500]
Sea -Spider	DEVELOPMENT STAGE	DEVELOPMENT STAGE	Magura V5 $ 273,000 [10] Marichka $433,000 [11] Toloka TLK-150 $200,000 [12]

To counteract these newly developed constrictions, the creation of low-cost interceptors is instead becoming a strategic prerequisite. This new kind of drones, deployed for the kinetic kills, make much more appealing, than conventional missiles. And while jamming and cyber warfare have their place in certain scenarios, they lose their potency when enemies are flying autonomous drones with encrypted comms and signal processors that withstand voltage spikes. But missiles, meanwhile, are too expensive and too inefficient to counter low-tech weapons.

The resultant kinematic interception of drones, be it through ramming, projectile discharge or physical retention, represents an effective and scalable defense response. While the above concepts would certainly help in dealing with airborne threats, the same approach must be applied to naval and sub-surface warfare as a matter of priority. Similar threats have been introduced to naval defense with the emergence of USVs, torpedoes, and UUVs. One of the more well-known was the German firms incredibly ambitious SeaSpider anti-torpedo system which never became a popular product (read, it didn't really work, or at least not for long) for the pentagon even though it tackled an enormous amount of technical challenges. However, the idea is far from dead yet and larger scale projects could eventually provide us with sturdy undersea interceptor platforms.

A low-cost interceptor makes sense due to the nature of warfare. The emergence of low cost, high impact drones have made drones a game changer on the battlefield. Kamikaze drones and drones swarms have shown it is possible to destroy a high-value asset, such as a tank, radar installation or even a warship, for only a fraction of the price of traditional weapons. That’s an unacceptable cost asymmetry: we can’t afford to defend ourselves against these threats with traditional systems of the past. When a $2,000 drone can be neutralized by nothing but by a $1 million missile, the defender is always at a strategic disadvantage.

Interceptor drones are an improved if not perfect approach by capitalizing on mobility, flexibility and decentralization. In contrast to fixed missile batteries, these drones can be scattered over broad areas and moved easily where needed, when needed. Their modularity also makes it possible to upgrade and modify them to withstand not only drones but fast moving surface or underwater targets. With more development, they might become multidirectional lines of defense, overlapping across air, land and sea.

To accomplish this goal, a variety of technologies and systems need to be developed and co-integrated in a single, low-cost package. A lightweight yet strong airframe is a key requirement, which can be made from carbon composites or reinforced plastics. Those materials may cut down on flexibility, but you get a reduction in cost to go with it. Propulsion, whether as a high accelerating brushless electric motor or micro jets, does not need to consider long endurance range. Drones also need built in sensors—optical, thermal, or radar—that can spot and follow targets in real-time.

Just as critical are the underlying layers of artificial intelligence and computer vision required to make the tech truly autonomous. RoleDecades of use by the SI has taught us that interceptors cannot be piloted in hostile territories. Drones must be able to recognize hostiles, take tactical decisions and act in co-operation with fellow interceptors with no lag. This calls for high-performance edge-computing hardware to execute ML models locally, eliminating dependency on cloud for data processing.

Regarding neutralization mechanisms there is a large range of kinetic solutions under analysis. Some drones could be configured to ram into enemy drones and destroy themselves in the process. Others could be employ a net launcher or retractable mechanical blades to take out targets with no explosive force. This could include light arms or directed energy weapons in more sophisticated productions. All interceptor drones will require secure, low-latency communication systems to facilitate remote control, or coordination in swarms.

But in the way, there remains some problems, after all. Shrinking processors and sensors to what can fit in a cheap drone is still a technical challenge, though. Energy efficiency is also an obstacle, because high-speed drones burn up a lot of power, and larger batteries would be heavy.

A second matter is that of target identification: if the system identifies the wrong threat, then there is a high risk of causing friendly fire or a waste of interceptors. Jamming resistance is critical since the adversary may try to interfere in Drone-to-Drone communication. In the case of maritime applications, underwater drones face additional obstacles like pressure resistance, sensor signal loss, and propulsion in dense media.

Among other strategic ideas, different open-source and modular approaches may be implemented so that the international research community and defense startups can pool resources into cheap innovation. Edge computing processors such as NVIDIA Jetson Nano or Google Coral offer a strong AI engine with limited space and power consumption. Biomimicry may be employed for propulsion-meaning that drone movements could be designed to mimic how birds, fishes, and insects conserve energy when they are on the wing or swimming.

Another promising technology approach would be mesh networking through low-earth orbit satellites or drone relays to provide a communications capability in GPS-denied zones. To make production scalable, partnerships with commercial manufacturers in the automotive or consumer drone industries can put the supply chain and cost efficiencies into place for mass deployment. Public-private partnerships, hackathons, and defense accelerators could also help drive fast development cycles and unconventional solutions that bring both academia and industry to the table.

In conclusion, the future of defense lies on adaptability, affordability, and autonomy. The age of symmetrical and expensive weapon systems is giving way to distributed and intelligent platforms. These interceptor drones, being multi-domain in nature operating at low cost against various threats, shall be vital to the homeland security strategy. It is postulated that these drones will not attack the traditional systems of air defense but will instead strengthen them into a resilient, layered network of defense. The metamorphosis in warfare articulates an absolute demand for such an approach.

VII. COMPONENTS REQUIRED

Core Airframe and Propulsion Units:

- Fixed-wing frame, depending on agility and payload.
- High power-to-weight propulsion so that it can enable rapid interception and quick maneuvers (motors, propellers, batteries).

Guidance, Navigation, and Control:

- Onboard autopilot and flight controller for autonomous or semi-autonomous operation.
- GPS receiver and inertial measurement unit (IMU) for accurate navigation.
- A target-sight system (orientation-based visual, radar, or RF) marks or directs hostile drones.
- Communication link to a command station for remote control and monitoring.

Detection and Targeting:

- Sensors for detection and identification of targets (Camera, radar, LIDAR, or acoustic sensors).
- "Friend or foe" identification system, so that it does not target friendlies.

Interception Payload:

- Kinetic impactor can destroy a target drone.
- Net gun or deployable net setup to tangle and neutralize hostile drone propellers.
- Interception payload extension, rotation, or deployment mechanisms (servo motors, telescopic arms).
- Optional: Electronic warfare modules for jamming signal disruption of hostile drone controls.

Energy Absorption and Safety:

Impact energy absorption device (hinge, damper, or flexible mount) to shield the structure of the interceptor drone upon impact.

Other Support Systems:

Onboard sensors (gyroscope, accelerometer, pressure sensor) for stabilization and flight safety.

Balancer or counterweight system for stability during interception maneuvers.

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VIII. DEPLOYMENT OF AN INTERCEPTOR DRONE

1) Detection and Tracking:

The kamikaze drone is detected by ground- or air-based sensors.
The command station assigns this threat to one of the interceptor drones and sends the target data.

2) Launch & Approach:

The interceptor Drone is launched either manually or from a container system.
It makes its way to rendezvous with the hostile drone autonomously or under remote control using real-time guidance and tracking systems.

3) Target Identification and Engagement Preparation:

When the interceptor drone arrives at the rendezvous point, an attempt is made to obtain a visual or electronic confirmation of the target using onboard sensors.
Interception payloads are deployed from their stowage position into intercept mode for optimum performance. (ram, net, harpoon)

4) Maneuver to Inspect:

The drone sharply maneuvers to bring its interception tool into contact with the hostile drone.
Impact energy is prevented from being transmitted to the interception device by shock absorbers or flexible mounts.
If a net's deployed, it entangles and disables the target's rotors.

5) Post-interception Actions:

The interceptor drone may deploy a parachute for safe descent and recovery after the mission.
It may also activate some audio or visual signals to allow for locating and retrieving it.

Fig. 1. Vogan-9SP Interceptor Drone [13]

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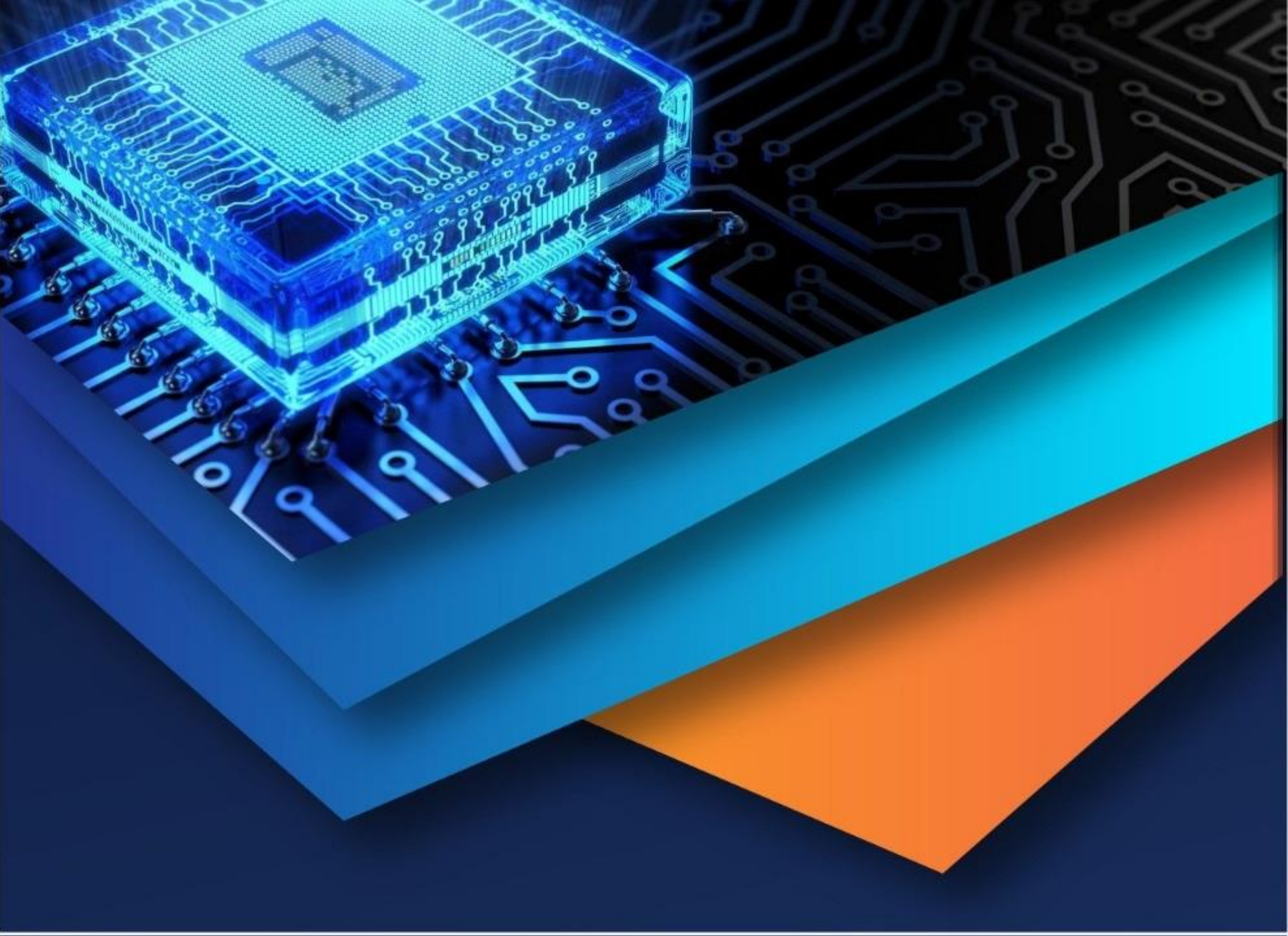

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