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Title: Unmanned Aircraft Systems for Security Applications

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Abstract: Unmanned aircraft systems (UASs) have achieved geometric growth in the commercial market and show promise for many industrial applications. UASs may also present an opportunity to aid in certain safeguards and security applications, including conducting complementary access inspections for uranium mines, deployment of radiation sensors for remote measurement and telemetry, additional security protocols involving tethered UAS, and other autonomous UAS used for site and material transport security. These systems may be able to help achieve nonproliferation and security goals of the International Atomic Energy Agency (IAEA) and partner nation sites by adding capabilities which were formerly either unsafe or technically infeasible. The current generation of UASs face constraints on range, payload, and maneuverability which limit the potential applications. Two- and three-dimensional imaging, volumetric assessments, radiation dose mapping, and hyperspectral imaging are some of the technical applications which UASs are likely capable of contributing to the safeguarding of mines. The implementation of UASs in safeguards and security applications presents several safety, security, and regulatory/political issues which must be considered and mitigated. However, none of these barriers appear insurmountable. The implementation of best practices in technology and training will ensure that the IAEA, operators, and host nations incur a minimal risk to safety, security and regulatory/political issues. This paper begins by outlining how UASs may help achieve safeguards goals within the application spaces of nuclear site security, material transport, and uranium mining activities. Current limitations are discussed, followed by a brief technical assessment of potential UAS capabilities which would be relevant to these areas. Future technology trends in UAS will be discussed on how they may impact the nuclear security and inspection missions. Finally, the paper presents a brief overview of related safety, security, and regulatory/political issues which must be considered.

1. **INTRODUCTION**

Unmanned aircraft systems (UASs or drones) have achieved geometric growth in the commercial market and show promise for many industrial applications. UASs may also present an opportunity to aid in nuclear security applications, including conducting security sweeps of fence lines, deployment of remote cameras and telemetry for alarm assessment, tethered UAS applications for long-term station keeping / static aerial missions, and other autonomous UAS used for site and material transport security.

The current generation of UASs face constraints on range, payload, and maneuverability that limit the potential applications. Two- and three-dimensional imaging, artificial intelligence/machine learning are some of the technical applications that UASs are likely capable of contributing to the security of nuclear material in situ or transport. The implementation of UASs in security applications presents several safety, security, and regulatory/political issues which must be considered and mitigated. However, none of these barriers appear insurmountable. The implementation of best practices in technology and training will ensure that operators and host nations incur a minimal risk to safety, security and regulatory/political issues.

This paper outlines how UASs may be applied to nuclear fixed-site security, material transport, and other security applications. Current limitations are discussed, followed by a brief technical assessment of UAS capabilities relevant to these areas. Future technology trends in UAS will be discussed in terms of how they may positively impact the nuclear security mission. Finally, the paper presents a brief overview of related safety, security, and regulatory/political issues that must be considered. For the purposes of this paper, only aircraft that fall into the small UAS definition, less than 55 pounds, will be considered. As a caveat, this paper will not make any statement regarding the use of UAS against nuclear sites or facilities by potential adversaries. While the authors recognize that this issue may complicate the decision space for adoption of these technologies, it is outside the scope of what this paper intends to address.

2. CONSTRAINTS ON THE USE OF UAS IN NUCLEAR SECURITY

Regulatory Constraints

If we discount the cost and training involved in deploying autonomous security UAS, the most significant constraints limiting drone operations in physical security operations at nuclear sites are regulatory in nature. Key among these is the restriction to require a human operator/pilot to always maintain visual line of sight (VLOS) with the UAS, and to limit the number of UAS that can be operated by a single pilot to one. This is the case with the U.S. Federal Aviation Administration's (FAA) Part107[1] regulation and is common for a number of other countries around the world. However, this is not the case for everyone. Figure 1 below shows the wide variation in small UAS laws with respect to operations beyond visual line of sight (BVLOS) as documented on the PetaPixel photography website[2].

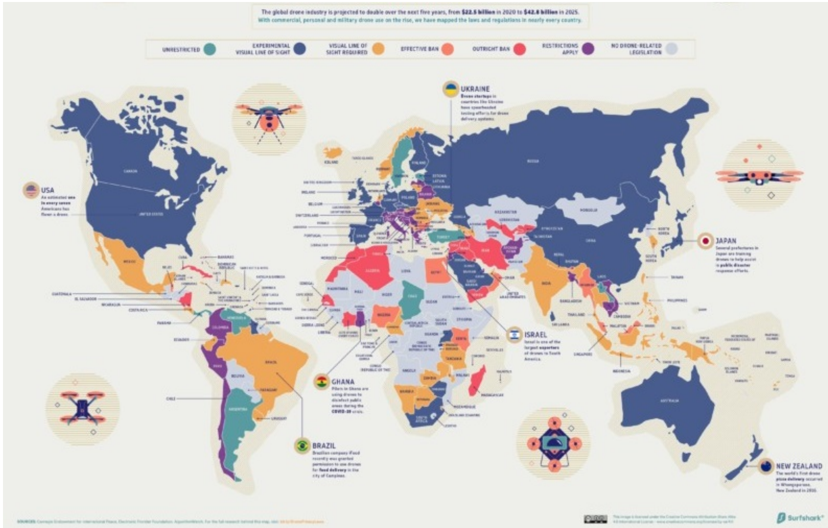

Figure 1. ***Small UAS Laws Governing Operation Beyond Visual Line of Sight***

In the United States, there does exist a waiver process that allows for BVLOS operations, but the granting of such waivers is still considered exceptional.

Another regulatory constraint that may need to be considered when implementing UAS for security purposes is the adoption of remote identification (Remote ID) systems by national aviation authorities. Remote ID gives them the capability to track the position of UAS in real time within their airspace. The U.S. FAA recently released updated rules as to what will be required with respect to Remote ID for commercial (and even some hobbyist) UAS in the near future[3].

Scalability

While UAS-based physical security is potentially a desired augmentation to the traditional security methodology, using single, manually operated UASs is somewhat impractical if we are considering using them across the entirety of the physical security domain in detection, assessment, and response. It represents a much more limited utilization of UAS, as opposed to the ability to deploy multiple UAS autonomously.

Operationally, manual deployment with a pilot requires both the time to get the pilot within VLOS of the launch area and whatever start up time is embedded within the particular system being utilized. In the case of a typical commercial off-the-shelf (COTS) UAS, this start-up time would include the time to transport the UAS to the area where it needs to be used, inserting a charged battery, and then launching the UAS. Drone-in-a-box[4] (DIAB) solutions improve start up time but are still fundamentally limited by the requirement of a pilot. An example of such a remotely deployed system is seen below in Figure 2 .

Figure 2. ***Percepto drone and base station***

Privacy and Safety Considerations
When implementing new technologies at any nuclear site, privacy and safety impacts must always be considered. This is made doubly so when considering implementing small UAS as a part of a physical security plan, as they open up their own "can of worms" as it were with regard to: 1) privacy of independent citizens, 2) impact on the cybersecurity, 3) safety of the site personnel, and 4) potential for the UAS to crash off-site / on-site. Therefore, great care must be taken during the planning and implementation phases of adding small UAS to the various site security technologies already in use.

Privacy: Countries, cities, and localities may have widely different regulations and ordinances regarding the collection of personal information linked to small UAS. It is critical to understand local and national requirements in this regard so that site security operations involving UAS remain within the bounds of the law. Valuable lessons can be learned by examining the use of small UAS by law enforcement and first responders, who have a slightly longer history of utilizing these tools. For example, it was reported by the Drone Center at Bard College in 2020 that over 1500 public safety agencies around the U.S. were utilizing small UAS in their operations, with 70% of those belonging to law enforcement.[5]

As with other technologies, addressing privacy concerns surrounding the use of drones involves a balance of policy and engagement. New policy should include a strong statement about the importance of preserving privacy rights. Based on existing policies for law enforcement, these uses could be potentially permissible with some restrictions:

- surveillance for physical security and accidents
- tracking potential intruders on site property
- monitoring dangerous situations

It should be noted that these privacy constraints would likely not be applicable toward employees of the site, who have no realistic expectation of personal privacy. Rather, they should be considered for UAS that point their cameras and other sensors outward beyond the fixed site perimeter.

Cybersecurity: Aspects of a site's cyber, physical, and cyber-physical security can be impacted by the adoption of new technologies, and none is this more evident than with UAS technologies, which potentially impact all three of these areas. Great care and deliberation must be taken when integrating commercial solutions into physical security network infrastructure at nuclear sites. Common considerations include:

- Are the signals, video streams, and telemetry that run between the command and control system and the UAS encrypted with modern protocols?
- Does the command and control system or the UAS itself require internet connectivity to accomplish any of its operations?
  Do software system updates for either the UAS or the command and control software go through a rigorous cyber-review, and/or do the updates originate in adversary countries?

Operational Safety**:** Safety must be the number one consideration in the integration of a UAS in a nuclear site security context. In general, safety concerns are focused primarily on the safety to personnel more so than to facility impact, as UAS tend to be small and fly at low altitudes, typically having negligible impact on the facility structures in the event of a crash. Autonomous operation over personnel may be explicitly prohibited by law, and the national aviation authority should be consulted. Autonomous operations that allow the UAS to fly over the security perimeter may only be allowed if the egress/ingress paths from the point of takeoff do not fly over common areas where site personnel are commonly present, such as parking lots, pedestrian pathways, etc.

Most commercial drones have embedded failsafe procedures that are automatically triggered when there is:

- loss of communications with the command and control or telemetry systems
- low battery / low fuel
- automatic detection of other abnormal conditions such as low temperature/icing, high wind conditions, and/or rain/fog

Typically, the detection of these failsafe conditions will trigger an automatic "return to home" action, forcing the UAS to take a safe operating altitude and proceed back to the position over its launch point or other designated safe point. It would then perform an automated landing. The success of this failsafe operation is reliant upon good sensor data from the GPS and altimeter. Other UAS are being designed with automatically deployed parachutes in the event of a catastrophic failure. ASTM published an international standard for small UAS parachutes in 2018 that is used as a reference guide for production of these systems.[6]

Technical Constraints

There will always be technical constraints that limit the abilities of small UAS. As the technology evolves, these constraints may lessen, but physics dictates that they will always be present in some form. These technical constraints include: 1) UAS range, 2) UAS altitude, and 3) payload size weight and power (SWAP). These are the three most common technical constraints, and they are largely bound by battery/fuel but also by regulatory constraints. Today, there are larger battery-powered multirotor drones capable of flying close to an hour (see AltaX[7]) and hybrid multirotor systems capable of flying multiple hours. One of these hybrids is the Skyfront Perimeter 8 UAV (shown below in Figure 3), which features a no-payload endurance of over 5 hours.[8] When payloads are added, the flight time is reduced. Fixed wing small UAS typically have a longer flight endurance time than a multirotor UAS but lack the maneuverability and ability to hover in one location that multirotor aircraft have.

Figure 3. ***Skyfront Perimeter 8 Hybrid Fuel UAS (unloaded flight time of five hours)***

POTENTIAL UTILITY FOR UAS IN NUCLEAR SECURITY

There is significant potential for small UAS to play key roles in nuclear site security. As indicated, the specific types of services that could be performed depend on many of the constraints mentioned above. There is a spectrum of UAS capabilities that can be applied toward this mission space, from fully manual radio-controlled flights with a pilot for each UAS, to an autonomous swarm of UAS that are capable of launching, flying preprogrammed or dynamic flight patterns (while simultaneously avoiding each other and other aircraft), and landing to self-recharge/refuel. Use cases that span the gamut of small UAS operations with respect to nuclear site security are outlined in this section.

Manual Operation Use Case
A manual operation use case would be typified as the use of a small UAS by security/response in an on-demand capacity. Generally, this is what law enforcement officials do when arriving at a scene and use small UAS to perform surveillance of the scene and to increase situational awareness. A nuclear site security officer could potentially use small UAS during a variety of activities or incidents that would benefit from either an aerial or remote view to oversee operations and/or minimize danger. These types of incidents would include but are not limited to:

- Security response while conducting official duties
    - surveillance of an adversary force or trespassers
    - surveillance of citizen protests for situational awareness
    - surveillance of activities that require additional security measures
- Accidents, Fires, Remote Inspection
- Vehicle Escorts
- Remote assessment of perimeter alarms

For this use case, the UAS could be part of the security/response officer's "kit" (i.e., equipment kept close by for responding to events). These UAS would typically be quite small (see Figure 4 below), capable of being transported on their person or stored in a security vehicle or within the Security Operation Center.

Figure 4. ***DJI Mavic Mini 2, small enough to be carried by protective force personnel***

UAS for on-demand manual to semi-autonomous operations can be stationed in an easily accessible external enclosures for quick deployment. In this case, the officer/pilot would need to get into visual line of sight of the enclosure and then allow some level of semi-autonomous operation (such as tracking an intruder/vehicle) to take place as they are observing the UAS within VLOS as the pilot in command, meaning they must have the ability to take over flight operations. As long as the autonomous operation occurs completely within the VLOS of the designated pilot (or an observer that is in contact with the pilot), the system would avoid regulatory issues present in many countries.

Autonomous Operation Use Cases
Fully autonomous use cases are significantly more difficult to achieve due to the regulatory hurdles previously discussed. With the evolution of new technologies and safer drone operations, however, the autonomous flight hurdle may soon fade. Interestingly, while this remains an issue in a majority of countries, some have no restrictions for autonomous flights at all (as was seen in Figure 1). Admittedly, the intersection between countries with lax drone regulations and countries with

nuclear sites is small. As such, addressing these hurdles with new technologies that enable safer operations is essential, and the DIAB systems are trying to resolve this. With enough of these types of UAS in place, the operator could perpetuate a 24-7 UAS presence above the site.

Autonomous Perimeter Sweeps

Security/response personnel can program UAS to remotely and autonomously patrol the perimeter of a property with an infrared camera, as opposed to having officers walk or drive the perimeter. Thermal imaging cameras can assist in rapidly identifying people amidst a cluttered background; and artificial intelligence (AI) features that rapidly analyze imagery acquired from UAS to identify people, animals, and vehicles are commonplace now. See Figure 5 below.

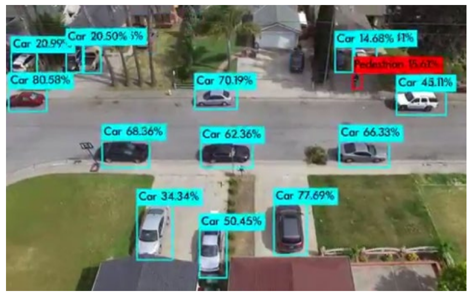

Figure 5. ***Machine learning and object recognition applied to aerial footage from small UAS***

There are many vendors offering both thermal and AI capabilities such as these, including: FlytSecurity[9], Airbotics[10], Nightingale security[11], Percepto[12], and FlytNow – home security.[13]

Autonomous Perimeter Alarm Response and Remote Assessment

One of the most promising areas for the application of UAS autonomy to nuclear site security is in alarm response and remote assessment. If an alarm is triggered, the geospatial coordinates of that event can also trigger sending an autonomous path plan to the closest autonomous UAS, instructing it to fly to the alarm location as it scans for intruders along the way. The vast majority of alarms that are triggered along fence lines tend to be false alarms induced by animals, weather events, or other nuisance alarm sources. This type of autonomous remote assessment has the potential to increase efficiency and cost savings for the site security force.

Autonomous Tethered Missions

Tethered UAS (TUAS) are gaining popularity as a way to avoid regulatory hurdles in some countries. They also offer other advantages such as:

- Significantly longer flight times, as most systems supply power to the UAS over the tether. Sandia National Laboratories (SNL) recently tested a power-TUAS that can run unattended all day and claims to run this way for up to 30 days.
- The ability for TUAS to follow their base station / tether reel system when mounted to a vehicle, which has the potential to give a patrol vehicle the advantage of 360° situational awareness of the vehicle surroundings and provide enhanced real-time situational awareness during nuclear material transportation activities
- The ability to rapidly deploy the TUAS in a new area of the site for inspection, situational awareness, and/or situational monitoring
- The ability to remotely deploy the TUAS as a compensatory measure if other observation/detection components of the physical security system become compromised

Examples of companies providing power-TUAS systems available to the market today are: Hoverfly[14], ZIYAN UAV[15], Blue Vigil[16], ElistAir[17], and AceCore Technologies.[18]

FUTURE TECHNOLOGY TRENDS IN UAS

New Trends in UAS Regulation

The U.S. FAA recently enacted new regulations that allow for the operation of UAS over people and at night. This rulemaking will likely have a positive impact on the use of small UAS in nuclear security operations as well, as it allows for more operational flexibility. These new regulations took effect in April 2021. Nuclear security sites will no longer need to apply for a Part 107.39, Operation Over People, waiver.

In addition, the FAA created four new categories for UAS. Each category represents a different level of operational risk that is based on the level of transferrable kinetic energy. Larger drones (categories 2, 3 and 4) can be flown over people with these new exemptions. UAS manufacturers and individual site operators will have to show a means of compliance with the safety aspect of the rule and receive approval from the FAA before being allowed to operate over people.

Similarly, site operators will no longer need to apply for the Part 107.29, Daylight Operations, waiver. Anti-collision lights are still needed, and operators will need to be tested to understand how flying the UAS at night presents unique challenges.

The U.S. FAA also ruled that, beginning 2023, small UAS must have some measure of remote, wireless identification (i.e., Remote ID) in order to operate in the national airspace. This should ease integration of small UAS into the larger National Air Space (NAS) and result in a net positive impact for using small UAS in nuclear security. The new regulation indicates that UAS weighing over 0.55 pounds (250 grams) must broadcast the operator's location and a unique identification number, like a kind of digital license plate.

TECHNOLOGY TRENDS IN UAS

Heavy Lift Capabilities

Small UAS are getting larger, meaning that the low-cost components that drove the explosion of the small UAS industry are continuing to benefit from the economies of scale and are dropping in price. As such, the total costs of heavy payload multirotor systems also continue to drop, while the capabilities continue to expand as shown below in Figure 7. The Foxtech Gaia MP line of UASs (with costs of $3,600 to $9,700 USD) has significant payload capabilities from 35 to 60lb.[19] Hybrid energy gas/electric UAS are now available in the $25k-$45k range with up to 30lb payloads. This trend will drive the adoption of larger, more powerful aircraft that have better ability to perform in adverse weather conditions and offer longer flight times, both of which will be net benefits to the use of UAS at nuclear sites.

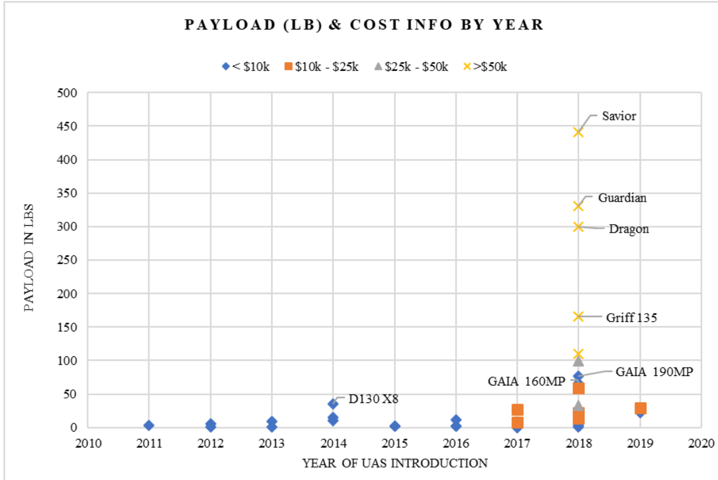

Figure 6. ***Multirotor Payload and Costs Information by Year***

Use of Artificial Intelligence/Machine Learning in Autonomous Flight Control Systems

Perhaps the most exciting technological trend we are tracking is the massive improvement in the capability of AI and machine learning systems to ingest sensor data from cameras and take autonomous action based on what it sees. There is no finer example of this than the small UAS produced by Skydio Inc.[20] Their current line of small UAS utilize six fisheye lens cameras feeding into a high-powered graphical processing unit (GPU) that is able to build a 3D map of its surroundings in real time, allowing it to avoid obstacles and autonomously navigate through complex 3D environments. This significantly reduces the potential for human error in collisions with buildings, vehicles, or structures. See Figure 8 below.

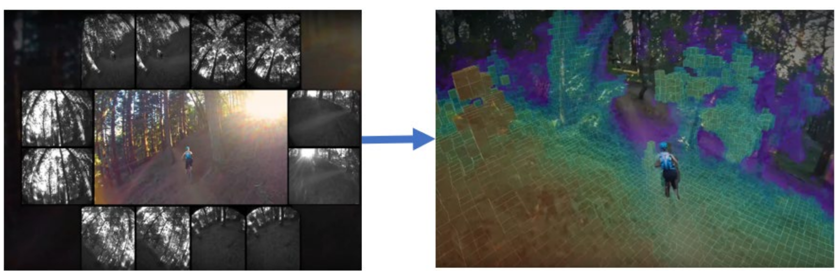

Figure 7: ***Skydio 3D Mapping for Autonomous Operations***

Almost all COTS small UAS that cost more than $1000 have some type of object recognition and tracking capabilities. This is all been driven by Moore's law, which the observes that the number of transistors in a dense integrated circuit doubles about every two years, allowing microprocessors to grow more powerful while simultaneously using less energy. This Skydio line of UAS uses six 4K cameras for navigation and a seventh for optical and infrared recording. Small UAS with 8K recording capability and AI that can keep up at those high resolutions will become the norm.

As new types of AI master the art of capturing human intent in natural language processing, small UAS will be imbued with capabilities to follow complex sets of instructions and directions. As individual identification capabilities improve, these systems will be able to learn all of the normal inhabitants and operations around a nuclear site and will be able to act on situations that appear in any way off normal, alerting security professionals to something amiss before anything tragic can occur.

CONCLUSION

The physical security of nuclear sites around the world is of paramount importance and, in the coming years, needs to be able to fully exploit advanced capabilities of small UAS. As we have shown, small UAS continue to improve and their applicability toward nuclear security applications has never been stronger. While there are still significant regulatory hurdles to overcome in many of the world's nations, as well as some technical challenges, the pace of technical evolution of these platforms is quickly addressing many of these key issues. This will enable the realization of:

- Safer operations of small UAS,
- Longer flight times and better payload capacities,
- Advanced AI capabilities to address security challenges,
- Cost-saving measures to improve efficiency, and
- The ability to provide better physical security at nuclear sites.

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