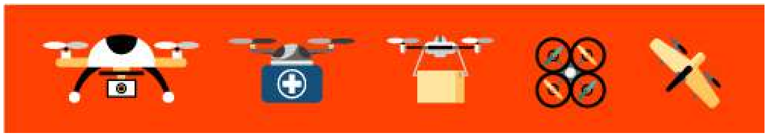
Robots in the Sky:
The Rise of Unmanned Aerial Vehicles and Intelligent Jamming

Introduction



Whether in the hands of a hobbyist or a soldier, an Unmanned Aerial Vehicle (UAV) in the wrong space at the wrong time can cost lives, millions of dollars and time. Consider the following high-profile situations:

• Five hundred million foreigners traveled to Brazil for the 2016 Summer Olympics. The largest of the stadiums held nearly 75,000 of those spectators for the opening ceremony. Events had attendance figures in the tens of thousands. Many competitions took place in open air. Eighty-five thousand security personnel were brought on to protect the games throughout the duration.

• As of August 2017, US military forces are engaging in active duty service around the globe. In Afghanistan, 8,400 troops participate on authorized commands to support Afghan security forces in the fight against the Taliban. Approximately 5,000 soldiers serve in Iraq to combat the Islamic State. Nearly 38,000 sailors on 53 ships serve in the US 7th Naval Fleet in the Pacific Ocean, undertaking air and water missions.

Innumerable vulnerabilities to UAVs, or drones, present themselves in these circumstances. A drone can be used to steal unauthorized footage of major events, interfere in commercial airspace, deliver military-grade projectiles and observe surreptitiously. As they explode into popularity and world forums address their use, knowledge of this technology is important across positions and industries.

This white paper presents an overview of UAVs: what they are, how they are used, and how to prevent these devices from interfering with operations. For the sake of clarity, this paper will use UAV and drone as synonyms. However, the term drone is more casual and increasingly refers to mainstream hobbyist devices while UAV is a technical term reserved for more advanced vehicles.

What is a UAV?

A UAV is a flight-enabled machine configured with embedded systems, such as system-on-a-chip (SOC) computers, and made of durable, light composite materials. In other words, they are robots that can fly at high altitudes. An embedded system differentiates a UAV and a remote-controlled airplane in the toy aisle. The primary purpose of a drone is to gather and harness aerial data.

How do drones operate?

Like a robot, UAV hardware runs software. Their operating software is either fixed or programmable, which means they can be remote-controlled or fly autonomously.

A fixed-software UAV is a device with a specialized capability. This type of drone would be more common for recreational or professional purposes. A photographer who takes aerial images of subjects — such as a cinematographer — would want a remotely controlled drone that bears non-lethal loads and is incapable of operating autonomously.

Programmable UAVs are more complicated machines because they are designed to be more, or fully, autonomous. Commercial, industrial and military purposes benefit from these systems. These "smart" UAVs are equipped with AI technology, sensors, cameras and smart precision actuators, with potentially lethal capabilities. A smart drone may receive a different command prior to flight so that it operates autonomously on a specific mission or receives instructions throughout its flight. Military drones used for engagements are prime examples of programmable UAVs.

How big is a drone?

Traditionally, a UAV is a small device, but there is a range of sizes. There are mini drones that can fit in the palm of a human hand, but there are also large drones the size of a footstool. A UAV for consumers tends to be good for indoor flying and thus runs smaller than professional-use or industrial UAVs. The latter applications require large frames that can support the onboard equipment necessary to carry out a mission. The largest prototypes max out at 500lbs of weight carrying capacity. Boeing's most recent UAV prototype rings in at 4ft tall x 18ft wide x 11ft long, similar dimensions to a Honda Accord. It's referred to as a cargo air vehicle (CAV).

What is a UAV?

How do drones fly?

Most UAVs are rotorcraft, which use rotors like helicopters rather than propellers like planes. They lift-off vertically, which requires less take-off space. The base rotor arrangement is a quadcopter formation (4 rotors) but it may vary depending on the UAV's application. Their ability to hover gives them better stabilization, a crucial element of videography and observation. Almost all drones also feature gyroscopes that smooth out the flight.

Military UAVs may use fixed wing technology. The most well-known of this type is the US Predator drone. These vehicles do need small runways for take-off, but they are still unmanned. A large, fixed-wing UAV might be used to survey a farm or patrol a wide area of vulnerable land.

Rotorcraft can run on electric, gas or hybrid power. Battery powered UAVs rely on Lithium ion technology, although that could change as battery research becomes a major field. Battery devices designed for recreational or leisure pursuits may see 20 to 45-minute flight times and one to two-hour charging periods.

Military grade craft can run for several hours, carrying out extensive missions. Some hybrid drones designed for advanced civilian activities can run up to four hours, with a distance range of nearly 100 miles — as far as New York City is to Philadelphia. New research by MIT on advanced UAV devices has produced a gas-powered drone that can run for five days at a time.

How do drones communicate?

All UAVs are equipped with a communication system. The ability to communicate drives the success of the drone. For most civilian and professional drones, radio frequency (RF) supports all transmissions.

RF communication is reliable, compact and uses little power. RF drones typically operate on the 2.4 GHz and 5.8 GHz RF bands. One channel carries ground-aerial control transmissions and the other relays information from onboard cameras. Drones filming sporting events use this system. One channel receives flight commands and the other relays video footage to a server.

There are a few downsides to RF signal communication. Relying on the popular 2.4GHz band may introduce issues of connectivity. Most wireless computer networks operate on

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this same frequency. A drone flying over a densely populated area may lose connection with its controller while competing with the abundant RF signals.

The UAV's reliance on RF channels creates another potential error: competition with onboard systems. The attached equipment may use RF signals for their own operations unrelated to the UAV control. If the main communication line uses all the bandwidth, those onboard systems will be effectively disabled, limiting the UAV's abilities.

The most inconvenient part of RF signaling is its line-of-sight (LOS) requirement. Controllers relying on RF must be within the UAV's LOS to maintain connection. If the drone can't "see" its pilot, then the link between the two will end. Unless the drone is preprogrammed to return to a base upon disconnecting from its controller pilot, losing LOS will ground it.

Military UAVs communicate over radio waves as well. However, UAVs engaged in sweeping military operations may travel out of an RF LOS within the first minutes of a mission. Therefore, in the field, they will use wave forms such as 802.11a/b/g/n, Time Division Multiple Access (TDMA) and Code Demand Multiple Access (CDMA). Some of the same issues can arise with these radio formats. Other communications solutions include 4G and 5G connectivity. For grounded UAVs, technicians may prefer to use cables. They may use a serial cable solution such as Ethernet, RS-232 and RS-422/RS-485.

In sensitive situations, these vehicles tend to rely on datalink communications, which are most often satellite based but can use other network methods. UAVs use satellite duplex data links, which means they both send and receive information. Although this method can introduce latency to the information, it will remain continuous. They must meet military standards and interface with data communication centers.

Datalink is more expensive and requires more telecommunications technology on the vehicle. To reduce the cost, military UAVs process and condense data on board before relaying it. As a result, this method is more secure, less prone to interruption and more compact than continuous, unprotected data streams across civilian RF channels. In a way, drones equipped in this manner function like edge devices.

New additions to UAV technology include cellular network downlinks and mesh uplinks as well as controls. The benefits to using mesh networks and cellular networks are the accessibility, coverage and security. Employing a UAV in an urban area with coverage would allow an operator to control the device without risking a more latent data link or competitive RF scenario.

What does a UAV do?

A UAV can complete a wide variety of tasks and contribute to a range of optimizing, cost-saving processes in many industries. Equipping AI software — such as image recognition, audio recognition and deep-learning capable processors — along with automating actions has been a key step in 2017 towards diversifying UAV tasks. Continued IoT growth and the expansion of edge computing have also broadened their accessibility. As with all technology, material science advancements have made them more durable across environments. Below are a few applications of UAV technology.

Military

The US Armed Forces received increased media attention about drone use during President Obama's first term from 2008-2012. However, the Predator RQ-1 UAV that was employed during the War on Terror made its maiden voyage in 2001, just after 9/11. Its original model had one job: scout out locations and relay video footage back to headquarters. Sealevel Systems provided integral serial solutions to the Predator project.

Over the decade of its use, the Predator was designed to bear lethal Hellfire missiles and carry out targeted attacks. A camera on board allowed US military intelligence to investigate the terrain, local populations and suspicious locations. A laser guide along with "smart bomb" technology was supposed to decrease the odds of civilian casualties by intelligently guiding its missile.

Throughout 2018, the military will be phasing out the Predator and introducing the MQ-9 Reaper, an offensive drone. It will run on satellite datalink control feeds with a two-man supervision system. However, it will carry more weapons with greater firepower over a longer distance: 1,150 miles vs the 770 miles of the Predator. It will likely include greater autonomy and improved camera technology along with surveillance AI software.

Agricultural

As early as 2014, MIT was reporting on agricultural drone applications. In those cases, sensors and simple imaging capabilities were helping farmers take measurements of their

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crops, driving up yield and reducing damage. Since then, the farming community has demanded more actionable intelligence than imaging.

With progress in AI visualization and pattern recognition, newer agricultural UAVs can help identify irrigation issues, soil variation, animal damage, pest infestations and even healthy vs. unhealthy plants. Automation has been another key factor in making these tools popular. With pre-programmable flights based on GPS coordinates and remote monitoring and control, UAVs can conduct surveys autonomously, returning real-time data without farmers micromanaging flights, as a manned aircraft would demand. New battery technology offers the biggest potential for UAV adoption in the agricultural market.

Manufacturing & Supply Chain

This industry uses the heavy weights of drones. Large warehouses, such as Amazon's facilities, have employed drones to carry packages, deliver goods, restock supplies and analyze inventory. The benefits of supply-chain UAV devices are their accessibility, availability and speed. With facility layouts programmed into their software, these autonomous bots run on a series of simple commands and simple AI.

However, what they offer in hard-to-reach places and small spaces they lose when it comes to mass transport, such as shipping. In certain instances, companies have made the cost worth it. Zipline delivery services transport blood and vaccines between hospitals in Rwanda. With the country's relatively small size, the difficult terrain and the specificity of the deliveries, it is far faster for medical goods to travel by UAV than truck. Zipline equips each UAV with a simplified cold-chain compartment that maintains the integrity of its cargo, preserving temperature and construction during flight.

How do you stop a UAV?

Stopping a UAV is a more complicated issue than first appears. Simply shooting a UAV down is not the answer for most individuals or agencies: it could carry explosives, hurt bystanders when it crashes or be a loss of valuable information. As a result, most research has turned to "jamming," a decades old technique that means interfering with radio signals electronically and blocking their dispatch or reception. Of course, as UAVs become useful to industries outside military and protection services, commercial applications for jamming have also risen. Globally, militaries have prioritized jamming research, but product developers have faced a few key obstacles.

First, a cutting-edge radio technology called Cognitive Radio (CR) gives drones an autonomous advantage against jammers and blockers. This installation gives a UAV the ability to communicate over the least busy channel available at the time of its transmission. The cognitive aspect of this process is that the UAV's computer analyzes available streams and chooses which one to relay information over. Advanced cognitive radios incorporate other AI tools, such as deep learning and data pattern recognition. A UAV with these additions is capable not only of detecting crowded channels but also unsecured channels. With an advanced CR installation on board, a UAV could autonomously evade jammers. However, CR technology is still in its infancy and it could be several years before the hardware exists to accommodate such a smart radio.

The ideal application of CR is for emergency services. Here, this "decision making" gives first responders and critical personnel access to information if RF signals are overloaded by crowds or diminished. However, CR can also be used to thwart jamming: the CR detects that the channel or frequency is being jammed and switches to an open avenue, thus side-stepping the jam. For military applications, avoiding an interference event is preferable. However, public safety officers will not want to chase a civilian drone evading their jam via CR capabilities.

A second major obstacle to jamming is the imprecision. A vast number of devices legally use RF signals and GPS locations. Employing traditional jamming tools can ground an illegally flying UAV but dangerously interfere with other acceptable air vehicle use.

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Obtuse jammers can affect ground stations, computers or servers nearby and other telecommunications equipment.

For example, consider a public airport. Each day, planes with trips approved by the FAA take off and land, relying on a complex series of communications during flight to ensure safe arrivals and departures. On the ground, civilian drone hobbyists may be flying an unauthorized UAV over protected airspace. Airport security services and ground control need a method of jamming the UAV without interfering with the airplanes.

AI and telecommunications advancements have earned efforts to improve anti-drone technology the moniker "intelligent jamming." Two primary methods of intelligent jamming have emerged for commercial and military interests: GPS jamming and network interference.

GPS-jamming

Autonomous vehicles garner most of their value from being able to fly without supervision. Using GPS, a UAV can follow routes, collect information about specific areas and return after a completed mission. A UAV that does not know its geospatial location proves itself useless. A lost UAV has the potential to be stolen or destroyed, which in military operations could compromise important data. If the GPS does fail, most UAVs have a failsafe programmed in its emergency response that automatically kicks in a "grounding" or "return to base" command.

New intelligent jamming technology works to block GPS signals to a UAV. It differs from traditional GPS jammers in range and specificity. Updated products can target specific devices emitting radio signals without jamming technology outside of its accepted range. Its precision comes from using integrated sensor networks, radar reports and video footage.

In a non-combative scenario, a UAV returning it to its base is the preferred result. It can show security services where the controller is, if there is a need to apprehend the remote pilot. In combative situations, grounding the device gives the officers on duty the opportunity to recover the device.

Hijacking

Even when a drone runs autonomously, it relays information back to a mission base system or receives new transmissions from that control center. For remote-controlled UAVs,

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there is a definitive, constant link between the vehicle and the controller. That link offers the potential for drone hijacking. In hijacking, a third party takes control of the vehicle and gives commands. Certain radio technology devices can be used, like jammers, to disrupt the continuous stream of signaling. After disrupting the flow, those controllers substitute their own signals for control. The UAV accepts the change and is controlled from then on by the third party.

Hijacking UAVs is a relatively recent addition to the smart jamming technology family. It debuted in 2016 at the PacSec Security Conference. Currently, this method of blocking is not publicly available and is primarily effective against hobbyist drones. These smaller devices rely on DSMX to communicate, the key to the hijacking. DSMX is an advancement in the RF communications field. It builds on the standard form of RF linking — DSM2 — and updates transmission/reception technology. DSMX components allow RF communications to be made over the whole 2.4GHz band whereas DSM2 just allows refreshing along two channels at once.

The future of UAV technology.

Since the initial balloon of the UAV market, leaders have been established and new companies entering the competition have diminished. Research and development is going towards decreasing the entry cost of UAVs for professional and industrial use, extending flight time and increasing durability. From a communications perspective, anti-drone and counter anti-drone technology will continue to be popular research fields.

As with all versatile robotics applications, it will be interesting to see how UAVs intersect with trends in the technology world, such as IoT and edge computing. As LoRaWAN technology becomes more prevalent and UAVs increase in size — capable of carrying larger processing centers — an aerial edge network could theoretically be created.

For example, a UAV equipped with LoRaWAN could connect to other drones within its network to create a surveillance cover. This application would be ideal for marine or agricultural supervision, such as conservation parks. The low-power demands of the network combined with its long-range capabilities would ensure consistent communication between autonomous drones. The LoRaWAN would not eradicate the need for a satellite link, however, as that component would still be necessary for communicating with a control center.

In the meantime, UAV adoption will level out until it can become both cost-effective and disruptive for a company to base a logistics operation on the vehicles. While legislative and governing bodies may be creating policies to limit unsafe use of UAVs, technology giants and military programs will continue investing in these aerial robots.