UAV WHITE PAPER

Spynel: A PROVEN SOLUTION FOR MICRO-UAV DETECTION

HGH Infrared Systems

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1. MICRO-UAVS ON THE RISE: DETECTION CHALLENGES

Over the past ten years, advanced developments in Unmanned Aerial Vehicles' (UAVs) technology have resulted in high levels of autonomy, versatility and performance with a wide range of applications, either civil or defense related. These missions include: reconnaissance, surveillance, crop-spraying, weather related missions, recreational or professional photography, but can also present very real security concerns, when put into the wrongs hands: smuggling (of weapons, drugs, cell phones), harassment (by activists or paparazzi), espionage or potentially sabotage and terrorist attacks are a few examples. Hacking also poses a threat if control of a UAV used during a mission is diverted by attackers interested in stealing proprietary data or the drone itself.

By 2020, the Federal Aviation Administration (FAA) expects to have as many as 30,000 drones flying in the United States.

CBS News reports that the top-selling drone - also commonly used for smuggling - can be bought on Amazon for anywhere from $400 to $1,800. CEA's U.S. Consumer Electronics Sales and Forecast report predicts that UAV sales will reach $130 million in revenue in 2015, 55 percent more than in 2014, with sales expected to reach 400,000 units.

Concerns are quickly rising as recent incidents have demonstrated the inability to detect and track the often cheap, slow moving, low profile targets with conventional sensors. Incidents have been numerous; on the border, around critical infrastructures, airports and prisons around the world.

Paraplanes have been used for years to smuggle drugs over the US Southern Border. They are hard to spot and can carry hundreds of pounds of payload. In 2012, CBP had recorded 223 ultralight incursions along the US-Mexico border. The drugs were unloaded to accomplices in the US who picked them up, while the ultralight returned to Mexico. Flying as low as 200 feet above the ground, ultralights are particularly difficult for radars to detect due to their wings being made of fabric and limited amounts of metal materials being used which significantly reduce the radar cross section. Recently, drug traffickers are turning to UAVs for smuggling drugs, in order to avoid accidents or being caught. Indeed, the Ultralight Aircraft Smuggling Prevention Act of 2012 increased the penalties for ultralight smuggler pilots: the law closed a loophole where ultralight aircrafts in drug smuggling were treated differently than larger aircraft. Now, the penalty can be a 20-year jail sentence and up to $250,000 in fines. Smugglers can also program UAVs to land at a specific location autonomously, which offers them an additional layer of protection. In January 2015, as rep orted by LA Weekly, a $1,400 drone was used to bring crystal meth over the border and ended up crashing in a parking lot in Tijuana.

Figure 1 - An image of a paraplane being used near the Southern Border.

A recent series of incidents where UAVs were spotted flying above nuclear facilities in France raised the concern of espionage and terrorism. The illegal flights performed at night were initially thought to have been operated by amateurs or pranksters. However, the UAVs that were used were more powerful and complex than the usual recreational drones: they were more expensive, helicopter-like models that can stay airborne for dozens of kilometers. A more recent incident involving coordinated visits to 5 nuclear reactors hundreds of kilometers apart escalated the French government's level of concern. A campaign of harassment by anti-nuclear activists could be the reason for the incidents, but authorities have not excluded possible surveillance flights by terrorists.

Prisons have also seen the rise of UAV threats in recent years, resulting in drugs and cell phones being smuggled over their perimeter fences.

In 2013, four people were accused of trying to fly a DJI Spektrum DX6i hexacopter carrying tobacco and cell phones into Calhoun State Prison, Georgia, as reported by BBC. On April 21, 2014, as reported by ABC News, a crashed drone carrying contraband (marijuana, tobacco and cell phones), was found in bushes outside the fence of Lee Correctional Institution, a maximum security prison in South Carolina.. Other occurrences were noted in Australia, Brazil, Greece, Switzerland, England, Quebec and Russia.

2. COMMONLY USED TECHNOLOGIES FOR THE DETECTION OF MICRO-UAVS

Multiple types of micro-drones are available, among them are multi-rotor (quad-, hexa-,octo-X8-rotor and Y6 rotor) and fixed wing UAVs.

Copter drones are typically slower and have a shorter range than fixed-wing models; even with battery extenders, most can't operate more than 30 minutes.

Fixed-wing UAVs are typically faster and can fly for four to five hours at decent speeds. They often require a runway or catapult which is not very maneuverable and they can't hover.

UAVs are usually detected using radar, visual detection or acoustic sensors. Because of the small sizes and small radar cross sections of UAVs, these methods of detecting them have become increasingly difficult.

RADARS:

Radars rely on detecting the electromagnetic waves (EM) emitted by the target. Small UAVs are non-metallic and due to their size, the EM signature is smaller, which makes their detection by radars very challenging.

Radars are also susceptible to interference from weather conditions, surface clutter (ground or sea clutter) and smaller flying objects (point clutter) such as birds, all of which can create a high level of false negative alarms or are eliminated altogether if filtered out.

ACOUSTIC SENSORS:

Acoustic sensors use microphone arrays to capture the sound of the moving parts of UAVs and compare the signature to a database of registered sounds for identification. The limitations of acoustic detection include:

- A high susceptibility to ambient noise and wind. Results in noisy areas will be poor.
- There are a large number of small UAVs available, as well as customizable parts, that require exact acoustic signatures be stored in the database for effective detection. Updating this data is time consuming and can eventually consume a lot of processing power. Glide mode is also very hard to detect, as UAVs become virtually silent.
- Last but not least, acoustic sensors can be very easily spoofed, by a change of component, a home-made customization or even by playing recordings of flying UAVs to confuse the sensors on the origin of the actual threat.

As opposed to the aforementioned means of detection, thermal technology doesn't require a library of ever changing UAV models and cannot be easily spoofed by a change in propeller or other components affecting the acoustic signature. In order to detect and track low-emitting heat and small targets, and to avoid false alarms, specific and advanced developments in thermal technology and algorithms achieved by HGH are now able to provide a superior detection capability at long range.

3. THERMAL TECHNOLOGY

Thermal technology is based on a simple physical principle: any object whatsoever, emits infrared radiation (IR). We call this the "infrared signature" of the object. This IR signature depends on a main parameter: the intrinsic temperature of the object.

Thermal technology is therefore used for two different purposes:

- Thermography: Thermography sensors analyze the infrared signature of materials in order to deduce their temperature without even making contact with these materials. Pyrometers, or industrial thermography cameras, are used for process controlor for temperature measurement in industrial furnaces, for example.
- Thermal imaging: thermal imaging cameras are not intended to analyze the temperature of objects but to capture all infrared radiation from a scene to render the most detailed image possible. The thermal camera provides the operator with a video that looks exactly the same day and night and is independent of lighting conditions (a sunny day or black, moonless night). Thermal imaging cameras are used for defense and security applications for day and night surveillance.

With thermal technology, it is impossible to be stealthy. Whether an object is hot or cold, it will be seen by the thermal imager, day or night. This is essential in order to understand the functions of Spynel thermal technology for UAV detection, whether they use a thermal engine or electric motor. Contrary to popular belief, a "cold" object is always seen by a thermal camera.

3.1. THE DIFFERENT THERMAL TECHNOLOGIES

There are two types of thermal cameras:

- "Cooled" thermal cameras
- "Uncooled" thermal cameras

The "cooled" cameras offer the best performance and the best image quality. While "uncooled"cameras are often more competitively priced.

3.2. HOW TO CHOOSE A THERMAL CAMERA

Two main criteria determine the quality of a thermal camera:

- Thermal sensitivity: is the ability to distinguish differences in temperature. The "cooled" cameras offer better thermal sensitivity than "uncooled" cameras. For the same number of pixels, the image of a "cooled" thermal camera is of better quality (i.e. less "noisy") than an "uncooled" camera's image.
- Spatial Resolution: is the camera's ability to capture very small details at great distances. The spatial resolution is closely related to the number of camera pixels. Clearly, the more pixels there are, the better the spatial resolution will be and the greater the detection range will be.

The most powerful thermal cameras on the market are therefore "Cooled" cameras with a large amount of pixels.

4. PANORAMIC SURVEILLANCE: THE SPYNEL INNOVATION

4.1. THE SPYNEL INNOVATION

The idea for the design of HGH Infrared Systems' Spynel series emerged from the following observation: thermal monitoring solutions for long range panoramic imaging must be developed specifically for this need, and not use traditional subsystems.

The SPYNEL systems are composed of two essential elements, developed by HGH:

- The high resolution panoramic thermal camera Spynel, which allows for the high speed acquisition of data.
- Cyclope software for data processing, visualization, detection and automatic tracking of multiple targets over 360°.

The Spynel / Cyclope tandem is more than a thermal camera: it is a single long-range automatic detection system that allows SIMULTANEOUSLY:

- Visualization of multiple targets over 360°
- AUTOMATIC detection and tracking of multiple targets 360° (terrestrial, maritime or airborne threats).

4.1.1. SPYNEL SENSORS

Spynel consists of an infrared camera that continuously rotates at a high speed (up to 2 Hz = 2 revolutions per second). HGH's thermal camera is capable of rotating at a high speed (which is impossible with Pan & Tilt cameras) while providing outstanding image quality with very high spatial resolution (up to 120 Mpixels for Spynel-X 8000).

The continuous rotation makes it possible to generate a thermal panoramic image after each camera turn. The successive panoramic images make a video.

Spynel can therefore produce a high resolution thermal panoramic image at a rate equal to the rotation frequency. This rate can be up to 2 Hz depending on the model. This ensures near real-time monitoring while the high spatial resolution and high sensitivity ensure high detection ranges.

Thermal imaging allows for day and night surveillance, but also guarantees the ability to view any object, even deemed as stealth, whether it is hot or cold.

4.1.2. CYCLOPE SOFTWARE

The Cyclope software is the intelligent part of the system. Without the Cyclope software, the sensor is simply used to provide images for observation purposes and no detection. The distinction between "observation" and "detection" is crucial.

The Cyclope software can generate automatic detections of intrusions that an operator could not pick up by himself through simple observation. It also relieves the operator from scanning the image permanently and missing a target during lapses of attention.

For nearly 15 years, HGH's teams have developed advanced algorithms for detection and tracking of all types of conventional and asymmetric threats: humans, vehicles, zodiacs, jet skis, wooden skiffs (pirates), ULM, helicopters, aircraft, drones...

The Cyclope software can be installed on industry standard PCs and includes a user-friendly, intuitive interface.

Cyclope offers multiple classification and recognition capabilities:

- 4x Digital zoom in zoom windows selected by operator in any direction
- Specific contrast settings can be selected for zoom windows for local area contrast enhancement as shown below.
- Basic classification of targets (ground or airborne) is based on elevation calibration. Air targets are represented by a small plane icon.

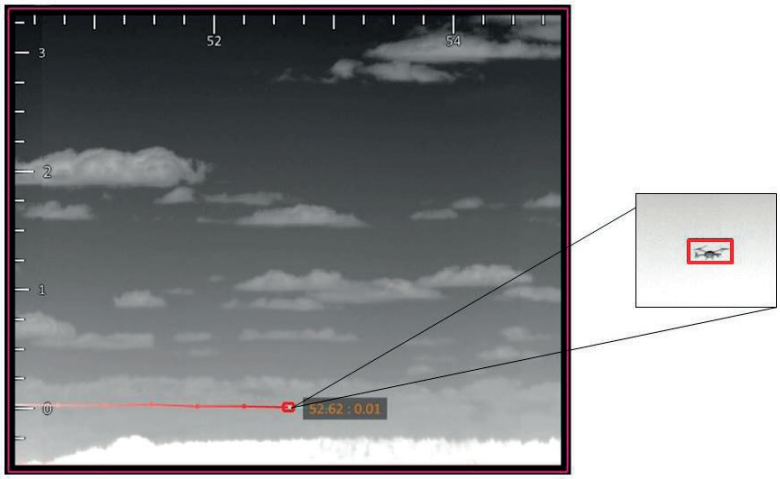

Figure 2 - A Cyclope screenshot shows a small UAV being detected and tracked

The main functions of the Cyclope software are:

CONTROL

- Quick set-up assistant.
- Remote sensor control and diagnostic.
- Control of tilt and water sprinkler (option).

DISPLAY

- Real time panoramic display (strip & annular).
- Multiple zoom windows on areas of interest over 360°.
- Automatic/manual contrast and brightness adjustments.
- Multiple screen capabilities (option).
- Graphical User Interface compatible with touch screen (option).
- Pinpointing or fast scrolling over 360°image.
- Multiple color palettes.
- Storage and playback of video sequences (timeshift function).
- MJPEG compression and video transmission through IP.
- Conversion and storage of video clip in .avi format.
- Screenshot in .jpg or .bmp formats.
- Access protection with login/password and history of sessions.

DETECTION & TRACKING

- Automatic and real time detection of multiple mobile targets (land, maritime, air) within the panoramic image.
- Bookmarks for manual classification of threats and forensic analysis.
- User-friendly setup of detection parameters (polygonal alarm zones, detection sensitivity, time set-up).
- 3D detection capabilities.
- Automatic creation of blips and tracks upon detection.
- Automatic tracking of multiple and simultaneous intrusions (zoom windows aim automatically at new detected targets without operator action).
- Tracking data available through IP (track number, date, time, azimuth, elevation...).
- Display of azimuth/elevation coordinates of detected targets.
- "Radar" view window with GPS position assessment of detected targets on site map.
- Capability to display permanently designated target parameters: azimuth, elevation, distance, GPS...

5. SPYNEL FIELD DATA

Many demonstrations have been organized by government entities in the US and abroad to check Spynel's capabilities to detect low-altitude airborne threats (micro or minidrones, paragliders, hang gliding, light aircrafts ....). Based on tests results, HGH was able to determine the most suitable model for each type of threat.

For the detection of UAVs:

- A vertical field of 20° is recommended. 5° and 10° vertical field of views (also available) offer greater detection ranges than 20° models, but air threats, even at low altitude, may be outside of their field of view. With a Spynel 20°, aerial surveillance is effective between 0m and 150m of altitude (or higher) from 400m away. Spynel detection range for mini-UAVs is well above 400m, so the Spynel 20° ensures detection of approaching drones, regardless of altitude.

- The higher the rotation speed of Spynel sensors, the better the detection and tracking of very maneuverable air targets (such as UAVs) by Cyclope software is. Having a higher frame rate will also trigger earlier warnings and provide valuable time to evaluate and neutralize the threats.

- The more pixels the 20° Spynel camera has, the better the detection range is.

COMPARATIVE TABLE - SPYNEL 20°

The three models proposed by HGH, and having a vertical field of view of 20°, are:

SPYNEL-C-1000

SPYNEL-S-2000

SPYNEL-X-3500

NOTE: The tilt of the rotating head of the Spynel-C, S and X can be adjusted up or down to adapt to the topography of the site and the application (air or ground detection). For the detection of drones, Spynel cameras are usually tilted upward so that the vertical monitoring area is comprised between the horizon (= 0 °) and 20°.

	SPYNEL-C 1000	SPYNEL-S 2000	SPYNEL-X3500
Horizontal Field of View	360°	360°	360°
Vertical Field of View	20°	20°	20°
Line Adjustable Referred	-20°/+45°	-45°/+45°	-45°/+45°
Flame Rate	Up to 2Hz	Up to 2Hz	Up to 2Hz
Spectral Band	LWIR (8-12µm)	MWIR (3-5µm)	MWIR (3-5µm)
Image Resolution	3 MegaPixels	7 MegaPixels	30 MegaPixels
Weight	28 kg	38 kg	38 kg
Operating Temperature	-40° to +71° C	-40° to +71° C	-40° to +71° C

6. EASE OF USE

With Spynel, panoramic detection and near-real time imagery work congruently: The operator has direct available images of all the targets at once and is able to quickly discern between targets of interest and targets that are generated by wild or domesticated animals, moving vegetation or regular activities. There is no such thing as a "lost track" because the operator keeps an eye on the threats at all times.

The Spynel display unburdens the operator: intuitively, watching panoramic images is less taxing than following a high number of dots and tracks on a map. Operators can get desensitized over time when faced with too much data.

With more than 100 Spynel units deployed, extensive feedback was provided from theater and HGH's engineering team automated all the Spynel settings, including the most complex ones, to make sure untrained operators or operators dealing with a large number of complex technologies, could successfully use the system. As a result, the Spynel doesn't require a dedicated operator: it can run on a customized screen, as part of a layered control and management system. It provides precious help in the early detection of real threats but also as a mechanism to collect ongoing intelligence for analysis and prosecution purposes.

7. FORENSICS

Spynel's advanced forensic capabilities allow the replaying of a sequence over 360 degrees as if it were live: all settings (color palette, zoom resolution, contrast, detection sensitivity, etc.) can be changed, which allows the user to pinpoint elements that were possibly missed previously. Additionally, bookmarks provide an easy way for the operator to mark and describe an event or a particular component from the scene. When looking back at the timeline, the analyst has a quick overview of all alarms and bookmarks.

The footage is time-stamped and can be used as evidence in court. Cyclope's zoom windows' footage can be saved on a CD ROM in a standard MSFT media format, and replayed without the Cyclope software.

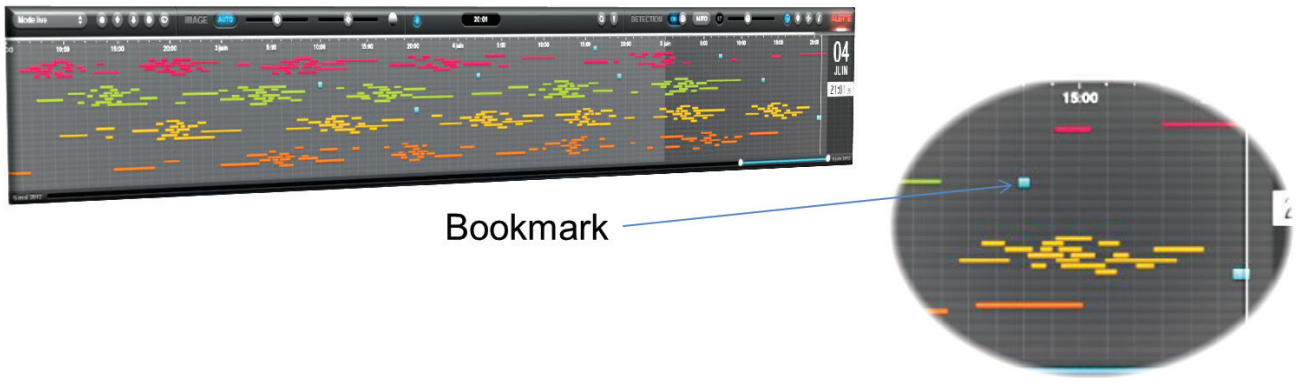

Figure 3 - Spynel's software timeline with color coded smart bookmarks.

8. MOBILITY

Vehicles equipped with surveillance solutions can be dispatched between fixed surveillance sites or in remote or inhospitable areas where fixed assets are not a good fit. As such, resistance to shocks, vibrations and dust, is paramount. The Spynel has been mounted on armored vehicles for the Army, off road, in the toughest conditions.. It provides quality high resolution situational awareness on the move and automated panoramic intrusion detection when stationary.

Benefits previously observed for fixed sites apply to mobile strategy. The advantages of a full panoramic, near real time thermal sensor is made more prevalent as the patrol vehicles venture out at night in areas with no external light or in treacherous terrain where full awareness of one's surroundings become highly valuable.

The Spynel system can quickly be operational; it is easy to integrate on a concealed deployable mast in the back of a vehicle or with a hardware kit that can be dismounted relatively easily. Spynel only requires an Ethernet cable connected to a ruggedized laptop and a power cable linked to a 24DC power source.

9. OPEN ARCHITECTURE AND PLUG IN ARCHITECTURE

Spynel systems use standard communication protocols for easy integration within other systems and can also display other sensors' detections on Cyclope's display for fusion purposes.

Users may also want to identify targets at the Spynel detection range, while maintaining wide area surveillance. This can be achieved through a slew-to-cue plugin that points a long range pan-tilt zoom (PTZ) camera in the direction of the detected target. A predictive algorithm ensures that the PTZ is pointed to the target. This plug in can be used to easily discriminate flying birds from micro-UAVs when Spynel's classification and recognition capabilities reach their limit.

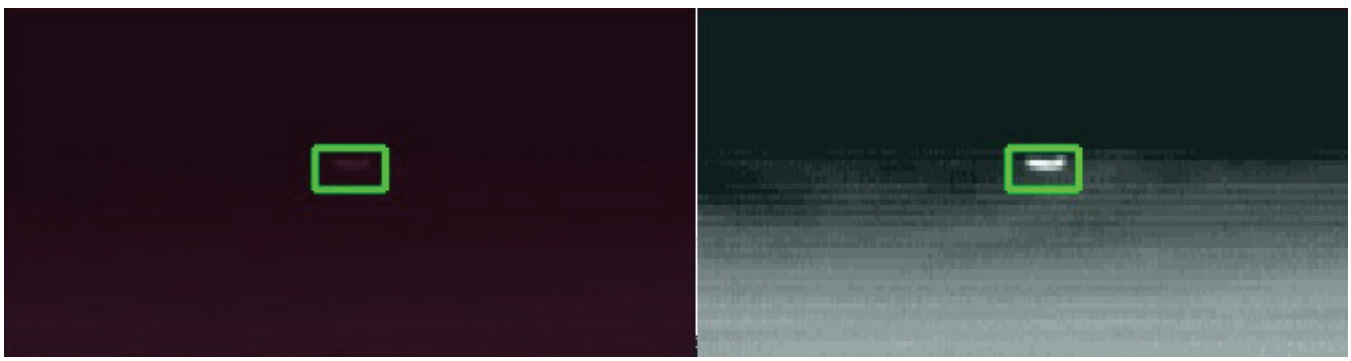

Figure 4 - Images of the same plane in zoom windows with two different contrast settings: a regular white hot palette on the left and an enhanced contrast palette on the right.

10. CONCLUSION

The Spynel system is a mature, COTS technology readily available for deployment. It is easy to set up and integrate with Common Operating Pictures software and other sensors such as long range cameras. Information can be sent back to a remote headquarter through wireless or fiber in real time, displayed in a central command room and stored digitally in a database for further analysis.

Spynel sensors were initially developed in 2006 and have been deployed in the harshest environments since their inception: Afghanistan for the US Army, the Middle Eastern desert to protect critical infrastructure or at sea in hot, humid and corrosive environments for the French Navy.

The MIL-SPEC Spynel is uniquely designed to provide full 360 degree situational awareness in near real time with automatic intrusion detection and tracking. Spynel is often described as "infrared radar": it provides the benefits of a thermal camera, visualizes threats day and night in total darkness, coupled with the benefits of radar as it automatically detects and tracks an unlimited number of threats in all directions at once.

For UAV detection, Spynel goes beyond other technologies' abilities: its proven detection range of micro-drones is unmatched and detection cannot be easily manipulated. Spynel, unlike radars, is completely passive and cannot be jammed. It does not operate with a library "matching" mechanism, and therefore can detect even newly released UAVs, or modified commercial models.

Spynel is the only reliable, proven 360 degree "thermal radar" with more than 100 units deployed to date and advanced detection algorithms developed over the course of 15 years.

About HGH Infrared Systems: Founded in 1982, HGH designs, develops, assembles and sells high end optronics systems for security, industrial and civil applications. HGH's team of highly qualified engineering team is comprised of experts in optics, software, mechanics and electronics and operates in France, at Igny (near Paris). HGH strives to provide advanced and innovative infrared equipment to protect their clients all around the world, while keeping the agility and dedication of a small and passionate team. Speed, flexibility, technical excellence and innovation constitute their core values. HGH has established itself as an international reference for infrared technology innovation through the development of multiple advanced thermal sensors, among which its award-winning real-time 360-degree thermal camera, the SpynelC 2008 Product of the Year from Photonics Tech Briefs, 2010 Innovation Prize from the EuroNaval Committee, 2011 Kummerman Award from the French Academy of Marine, 2012 GovSec Platinum Award.

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