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Radio silence

Icarus' swarming control architecture doesn't use radio comms but is designed around embedded UAV behaviour algorithms, as **Rory Jackson** explains

While there has been a lot of talk over the past decade on the subject of swarming for unmanned systems, only a few companies have successfully commercialised swarm operations. Icarus Swarms is one of those, having deployed its swarming capabilities in coordinated light displays, initially at commercial UAV shows.

Over the past year, the French company has also worked on providing critical applications for the country's special forces, revolving around key equipment to operatives on the ground at crucial tactical moments. The equipment can include radio relays, jammers, radioactivity sensors, EO or IR spotlights or cameras, or pyrotechnics for generating smoke to provide cover for the operatives when they're regrouping or withdrawing from a theatre of operations.

"We use standard COTS UAVs but customise them with some electronics and software to be able to field them in centimetre-accurate paths without mistakes across the fleets," says Icarus Swarms' co-founder and technical director Jean-Dominique Lauwereins.

These customised UAVs are now sold in turnkey batches, for use by organisations in the defence, security, emergency services and similar applications.

The technology used by the company is the result of more than 10 years of UAS research, and first tested in collaboration with Thales in 2009.

Small UAVs in swarms

For its base platform requirements, Icarus Swarms maintains a close partnership with consumer UAV company Parrot, which has supplied its quadrotors to the company for many years and given its engineers access to making the required hardware and software modifications to enable their approach to swarming.

While a few different craft can be used by Icarus, the UAV of choice tends to be Parrot's Anafi Thermal. This multi-rotor weighs 315 g, and is powered by a 2.7 Ah battery with two lithium-polymer cells to give a maximum flight time of about 26 minutes between charges.

Lauwereins notes that although these UAVs come with their own EO/IR cameras, Icarus Swarms will often integrate an additional and different

Icarus Swarms can fly groups of COTS UAVs in coordinated formations, for light shows and now for French special forces (Images courtesy of Icarus Swarms)

payload. The system in most demand is an IR spotlight, as soldiers' IR goggles are more effective for real-time thermal vision, and IR spotlighting enables them to see objectives more clearly without providing illumination for terrorists or paramilitary groups.

Icarus has also adapted and used Parrot's Bebop 2 UAVs in internal tests of its swarms; the Bebop 2 weighs 600 g but Parrot has now discontinued it. As Lauwereins notes, Icarus populates its swarms with small, inexpensive UAVs, so that end-users don't incur high replacement costs in the event of breakages or losses of craft.

"Also, smaller UAVs with smaller propellers generate less noise than bigger craft," he says. "If you're operating in an urban environment or conducting missions at night when you need some element of stealth, that's very important."

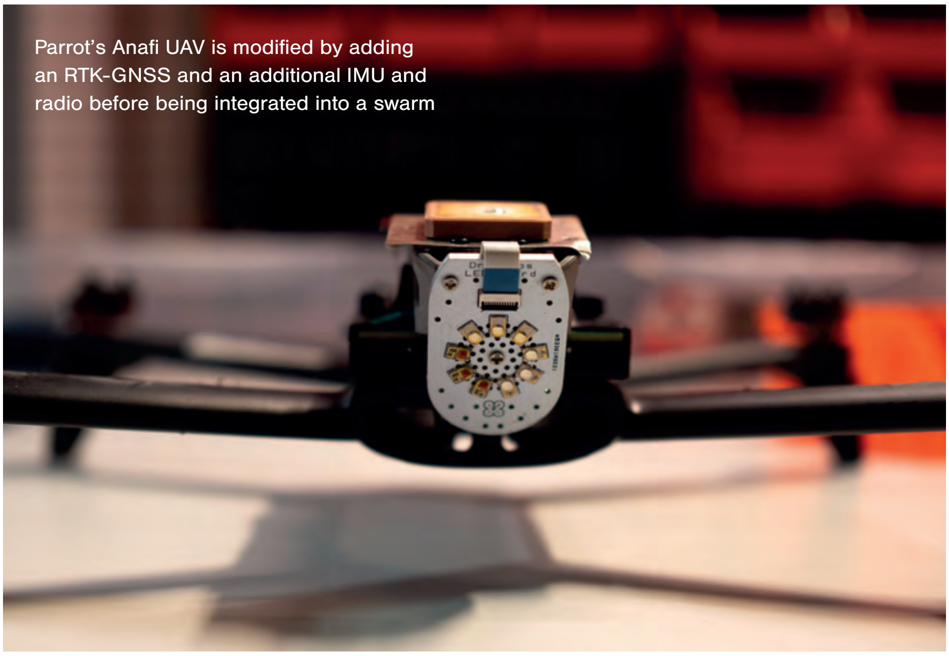
While the Anafi is lightweight and nimble, its small size means it cannot carry much weight. To make up for that, Icarus can use larger, more powerful UAVs upon request, such as multi-rotor models of up to 8 kg.

Smaller UAVs with smaller propellers generate less noise than bigger craft, which is very important when you need some element of stealth

Parrot has given Icarus access to its APIs, which enables the integration of several key systems. On the hardware side, Icarus has an assembly line for installing an RTK-capable GNSS, secondary radios and IMUs for redundancy, a compass for heading measurements, the requested mission payloads, and some adjustments to the electronics to improve comms fidelity between the processor and other onboard components.

The swarming software however comprises the bulk of the company's r&d work over the past several years. It provides the necessary logical algorithms for collective path planning and failsafe reactions across the UAVs in each swarm, and simplifies the user interface so that operators can focus on plotting and achieving their objectives.

As mentioned, the company supplies its UAV swarms as turnkey products, so their operation and use are far removed from the actual software underpinning their swarming capability. This is necessary for such complex technology, if end-users are to adopt it and derive value from it without first needing extensive training.


Parrot's Anafi UAV is modified by adding an RTK-GNSS and an additional IMU and radio before being integrated into a swarm

Icarus' standard product is therefore a 20 kg case containing 20 UAVs that are ready to be placed, programmed (with waypoints and altitudes) and launched in less than 20 minutes.

"So far, with our users in the French special forces and other security teams, we're finding that 20 is a good number for their operating requirements," Lauwereins says. "Any more and it would be problematic for their missions, because they often have to get themselves and all their equipment into the limited space of a helicopter or armoured vehicle at short notice."

He adds that his team's algorithms are also compatible with the software on the Parrot UAVs used by the US military, as well as the new variants of the Anafi to be developed by Parrot for the French military.

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Icarus' swarming technique

Discussions over the past several years regarding how swarming might be achieved have looked at centralised, fixed comms networks between a GCS and a group of UAVs, and various forms of decentralised ad hoc networks, in which swarms communicate and make low-level decisions internally to achieve high-level objectives.

The nature of Icarus' swarming control architecture completely avoids the use of comms however. Instead it uses intelligent embedded algorithms that predefine the full set of possible actions (including reactions to obstacles and failure modes) that each UAV might need to perform, and to streamline the end-user's planning process through intelligent group formation-plotting.

"There are many theories about how swarms will one day choose their own formations and adjust them dynamically by communicating their position, heading and objectives to each other," Lauwereins remarks.

"But as far as we've seen, those theories go beyond what the market is actually demanding for now – unmanned aircraft by themselves are still new to a lot of people.

"And whether you're giving a light show or in a military or civil operation, the worst-case scenario is often that one or many non-autonomous UAVs lose their data link or GNSS link, and then have to decide what they're going to do in the absence of comms with their human operators or other vehicles. So we really need our UAVs to be smart without needing any radio comms."

It is critical therefore that before any mission begins, each UAV is embedded with algorithms to define its behaviours at critical moments.

"For example, if at any point one or two UAVs become 'lost', owing to a failure in their GNSS receiver or a similar malfunction, they need to know how to return to the launch point," Lauwereins explains.

"The easy solution is to pre-assign a different altitude and set of inertial navigation targets in the algorithms to each one for their return route, so that they avoid collisions while returning to the same spot."

Beyond this example, however, the variables of a mission can run far wider, so Icarus' algorithms are designed to contain failsafe behaviours covering far more combinations of events – and permutations of their scales as well as distribution among each UAV swarm – than just this.

Once the mission has been planned, each UAV will be launched with its own exit path, to ensure that a safe return is possible for every one of them at any moment without collisions, and without the need for any comms with the GCS or other UAVs.

Before take-off the 20 UAVs of a given swarm must be calibrated while pointing in the same direction to ensure heading accuracy

A secondary processor provides for battery management, integrity checks of the main processor and cut-offs of battery power in extreme circumstances

Pre-launch configuration

Each carrying case contains the UAVs and a dedicated control laptop from Icarus. The laptop serves as a GCS but can work offline using preloaded maps of the area to be worked in and an encrypted local network connection for communicating plans to the craft.

This enables the swarms to be plug-and-play systems, so that end-users do not have to connect to a cloud or worry about wi-fi availability in their area, and hackers cannot gain access to a swarm.

Once the UAVs are switched on and connected to the laptop, they are calibrated with regard to the direction they are facing, to orient their GPS compasses. That takes about 30-40 seconds and consists of positioning them to face the same way and in a direction given by the laptop to configure their level of heading accuracy.

The operators can then input high-level objectives for the UAVs. These include GNSS coordinates and altitudes where they want their payloads flown, how long they want them in use there, and some points regarding the approximate strategy to be carried out. Much of this, such as formations and collective uses of tactical payloads, are preset and can be selected in the software's menus.

"The UAVs will coordinate themselves towards the higher-level mission objectives," Lauwereins says. "For example, if a user wants 30 minutes of aerial spotlight illumination at a given spot then, since the Anafi has 25 minutes of maximum endurance or 15 minutes of realistic operating time with payloads, the swarm will automatically plan the rollover.

"That will mean a trade-off in terms of how many UAVs can fly. If at least one UAV's maximum battery life would be exhausted in carrying out the objective, at least one will stay behind to take over afterwards.

"Or, if you want radiological scans over an area for an hour, say, then the software would probably coordinate the launches in four waves with five drones at a time, or five waves of four at a time."

Currently, the payloads are hard-fixed to the UAVs before they are delivered to the end-user. Customers working in area security for airports, power plants and similar zones for example might therefore have 10 UAVs with spotlights and 10 with remote loudspeakers, for seeking and warning trespassers.

"That reduces set-up time by quite a bit, which is most important to our end-users," Lauwereins says. "And although we aim for 20 minutes, the most recent trials with special forces found they could manage the whole set-up within 10 minutes.

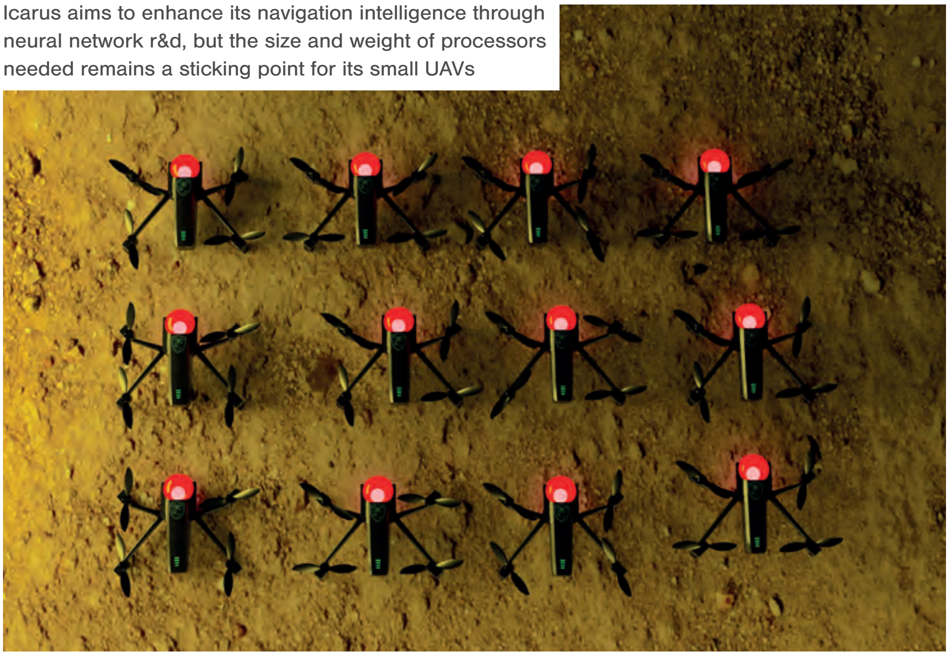
"If end-users want more payload flexibility, however, we can provide that. It might mean making a swarm using a low-cost, small UAV with a hot-swappable payload interface, or making an Anafi swarm with 30 to 40 drones with a diversity of payloads among them. Technically, we could supply a combination of these two approaches as well."

In-mission security and safety

As mentioned, the UAVs fly without having to be connected to the GCS – only a GNSS link is needed to check that position readings match flight plans, with the laptop enabling set-up before launch and monitoring afterwards.

A radio link for observing the Anafi

Icarus aims to enhance its navigation intelligence through neural network r&d, but the size and weight of processors needed remains a sticking point for its small UAVs



UAVs from the GCS is supplied encrypted and ID-secure when they are delivered by Parrot. The security of the UAVs' operations is therefore further enhanced, as they cannot be remotely accessed or controlled without specified security keys.

"Not all the UAVs we use are like that," Lauwereins says. "For example, for the Parrot Bebop 2 we have to add security and safety features similar to those on the Anafi. It's very important for special forces that the UAVs' video streams can't be viewed by hostile agents, let alone their control be taken over."

As mentioned, various failsafes are included in the Icarus algorithms to perform autonomous corrective actions, such as inertial-based return paths for GNSS failures, as well as auto-calibration of the IMUs, compass and barometer in mid-flight if their measurements show indications of instability or other failures.

"Correcting bias on-the-fly is very difficult, but it's important that our UAVs can do so, particularly since these sensors are very sensitive to temperature and many of the special forces' preferred payloads and environments will heat the sensors' electronics considerably," Lauwereins says.

Lauwereins adds that as well as the various hardware and software modules installed on its UAVs, another processor is typically integrated on each craft for dedicated battery management, as well as monitoring the performance and fidelity of each one's main CPU, as a final safety measure.

The main CPU monitors this safety processor in turn to intermittently confirm it is operating nominally. Also, the processor has the authority to cut off battery power in the event that a severe malfunction is happening, or if it is decided that a UAV has to be destroyed by letting it fall out of the sky than risk its technology falling into enemy hands.

Post-flight maintenance

Once the UAVs have completed an operation, they return according to their predefined routes and timings. Their landing coordinates are typically at the same rough locations as those they were launched from, although Icarus recommends that when they land they are spaced at least 2 m apart to ensure there are no collisions.

The company also supplies extra battery packs, wall chargers and some specially designed charging equipment for operators to replenish their UAVs' batteries between flights and thus help sustain operations for as long as required.

"It's nothing too complicated," Lauwereins says. "For example, we can provide a case that will charge up to 120 batteries at once, with two plugs to draw sufficient energy from a generator, external power pack or wall socket."

Once all the UAVs are recovered, some basic maintenance tasks are recommended, although much like the rest of their systems the company has sought to keep these as simple as possible. For example, visual checks for broken propellers, removing and recharging batteries, and diagnostics of any failed components or UAVs can be performed; any repairs or replacements should be carried out by Icarus however.

Future plans

The technology is continuing trials with French special forces, and active operations of the systems outside France are anticipated in the future.

Meanwhile, Icarus continues to develop its technology for a range of other uses. For example, it offers swarms as part of its Certifence product, in which up to 1000 UAVs can be deployed into an area protected by a counter-UAS system to test its ability to detect and potentially mitigate the threat of the trespassing Certifence UAVs through non-destructive or destructive means.

"We're also looking into the challenge of flying hundreds of UAVs safely through a city," Lauwereins says. "That's very different from light shows for entertainment, where the drones are flying over a stage, but in the future we're confident that we'll be able to conduct important commercial operations in city skies with all the safety and reliability needed.

"One thing we're really looking forward to are advances in CPU power. We are currently working on neural networks for even more intelligent ad hoc navigation and other behaviours, but either CPUs will need to get more powerful or neural networks will need to get smaller before we can use them in our small UAVs."