WATER AND TECHNOLOGY

The age of the drone – Keeping an eye on the nation's water

Drones are taking to the skies for a variety of water-related applications. Article by Sue Matthews.

Time magazine dedicated much of its June 11 issue to a special report on 'The Drone Age', and used 958 tiny drones flying in formation to recreate its iconic cover design. The international open-access journal *Water* is calling for papers for a special issue entitled 'Water management using drones and satellites in agriculture', and many scientific and industry conferences nowadays include a session on the use of drones, or unmanned aerial vehicles (UAVs).

It was drone footage of the Western Cape's nearly empty Theewaterskloof Dam that brought home the stark reality of the drought to many Cape Town residents, perhaps prompting them to intensify their water-saving efforts. At the other extreme, drones were used to map the extent of flooding and assess damage to property and infrastructure during the UK's disastrous 2015-2016 floods. The Drone Watch project, led by Cranfield University and funded by the Natural Environment Research Council (NERC), provided detailed aerial imagery at a time when heavy cloud cover compromised the ability to get optical satellite data, and where synthetic aperture radar (SAR) satellite data – able to penetrate clouds – could not easily distinguish water from urban features.

Drones clearly have advantages in terms of providing a bird's eye view and being able to reach relatively inaccessible locations, while also offering better spatial and temporal resolution than satellite imagery. They do have a number of limitations, however, the most restrictive of which is the regulatory environment, particularly in South Africa. The addition of a chapter on Remotely Piloted Aircraft Systems (RPAS) to our Civil Aviation Regulations effectively grounded many drone operators when the amendment came into effect in July 2015, at least until they could comply with the stringent registration, licensing and certification requirements.

Flight time is also a severe constraint – most of the smaller drones cannot stay airborne for more than half an hour before a change of battery is needed – while wind and rain may make flying conditions unsuitable. Large fixed-wing drones are hardier and can typically fly further than multi-rotor drones, but are in any case limited by the need to remain within view of the pilot at all times, and no further away than 500 metres. An accredited training course for beyond visual line-of-sight (BVLOS) certification has only recently become available in South Africa.

Fixed-wing drones have the disadvantage of being unable to hover or to fly slowly enough for the particularly high-resolution data collection required for certain applications, and most need a runway to take-off and land, although some innovative designs have overcome this limitation. The 'Eagle Owl' manufactured by Aerial Monitoring Solutions, for example, comes with a foldable aluminium launcher and a parachute for retrieval, while Passerine Aircraft Corporation's 'Jumper' has bird-like legs that allow the drone to launch itself into the air and land. Both these companies are South African, based in Johannesburg. In fact, the CSIR has been building drones since the 1970s – primarily for military surveillance and border patrol purposes – and is soon to release an updated design of its Long Endurance Modular UAV (LEMU). The 'petrol version' will have a flight duration of eight hours and a payload capability of 20 kg, allowing it to carry instrumentation for a range of different applications.

Looking at water-related applications, specifically, there are a variety of ways in which drones are being used, both locally and internationally.

Agriculture

The agriculture sector has seen the most uptake of drone technology for water-related applications in South Africa. Drones not only provide an overall perspective of farmland that is impossible to glean from the cab of a bakkie, but can also facilitate 'precision agriculture' – the right input (be it water, fertilizers, pesticides or seeds) in the right amount at the right time and in the right place. Apart from helping to optimise production and minimise wastage, this reduces runoff and hence the pollution of nearby water resources.

Precision agriculture has been taken to a new level with the recent arrival in South Africa of crop-spraying drones, but given the advanced qualifications required to fly them, their use is currently very limited. More typically, farmers are using multispectral sensors on drones to get a picture of crop health via Normalised Difference Vegetation Index (NDVI) mapping, so that they can identify areas of plant stress. NDVI compares reflected red versus near-infrared light, because healthy plants absorb red and blue light for photosynthesis and strongly reflect near-infrared light, while stressed plants reflect more red light and less near-infrared light.

"Once you see there's a problem area, you can go out there and figure out whether it's because of too much water or too little, nutrient deficiency, or some kind of pest or disease," says Arie van Ravenswaay of the Western Cape Department of Agriculture. "Alternatively, if you have a thermal imaging camera on the drone you can tell whether water is the issue, because moist soils will be cooler than dry ones."

The latter method could also alert the farmer to leaking irrigation pipes. Another common use of drone imagery in agriculture is the generation of digital elevation models (DEMs) to inform planning and design of irrigation and drainage systems. Of course, the processing and analysis of drone-captured data for these kind of applications is generally beyond the skillset of a farmer or drone pilot, and uploading massive files to online services can be problematic in rural areas with slow bandwidths. Most drone operators have therefore formed partnerships with agricultural consultants and data-analytics specialists, and farmers can opt for subscription services that include user-friendly mobile apps and desktop software. Cape Town-based Aerobotics, for example, uses machine learning to interpret drone imagery for tree crop farmers, providing them with information on the health, size and canopy area of individual trees, and identifying management zones to plan irrigation probe placement, soil and leaf sampling, and variable-rate fertilizer application.

Wetland assessment

Environmental scientist, Marinus Boon, effectively demonstrated the benefits of drones for aquatic research purposes when he conducted South Africa's first study that used UAV photogrammetry as a tool for wetland delineation and health assessment. The initial research, undertaken for his MSc degree at the University of Johannesburg, used an off-the-shelf digital camera mounted on a multi-rotor drone to take some 1 200 photographs of the study site – a 100 ha channelled valley-bottom wetland system adjacent to the Cors-Air model aircraft airfield in Gauteng.

Together with 20 surveyed ground control points, the photos were processed with Structure-from-Motion (SfM) software to derive ultra-high resolution point clouds, orthophotos, digital surface models (DSMs) and digital terrain models (DTMs). These products allowed for fine-scale mapping of the wetland, with vegetation, inundated areas and features associated with disturbance – for example, invasive alien trees and grass, impoundments, excavations and erosion gullies – all clearly identifiable. Information on factors such as slope, drainage channels and flow impediments provided insight into the movement of water through the wetland, improving understanding of its hydrological functioning.

Subsequently, the research was expanded to include UAV multispectral imagery, with NDVI mapping being used to refine the extent of hydrophilic vegetation and degraded areas in order to assess wetland vegetation integrity. Repeating such surveys over time will allow changes in the wetland to be monitored, and the results used to inform its management.

Marinus has combined his expertise in drone-based technology with his long involvement in the environmental planning industry by establishing a consulting company, Kite Aerial Imagery, to provide 'UAV imagery for better environmental decisions', according to its slogan. He points out that the high-resolution images and detailed data obtained using drones have an important role to play in assessing environmental impacts, because they allow engineers and environmental practitioners to visualise a site and understand its full context even if they cannot visit it.

The Riverscapes project, conducted by a consortium led by the Technical University of Denmark (DTU), is developing a drone-based monitoring solution that delivers hydrometric and ecological data to inform catchment-scale risk assessment, channel maintenance and climate change adaption

Riverine assessment

Drones also have considerable potential for the assessment, monitoring and management of river systems. The European Union's Water Framework Directive, for example, requires classification and monitoring of the ecological status of rivers in terms of biological, hydromorphological and physico-chemical elements. The Technical University of Denmark (DTU) is currently heading a collaborative project named Riverscapes, which aims to develop a drone payload package comprising cameras, sensors, radar and sonar instruments to deliver datasets on water surface elevation, bathymetry, water surface velocity, thermal maps and narrow-band spectral reflectance of land and water surfaces, and high-resolution digital surface models of the stream environment. Project leader, Prof Peter Bauer-Gottwein, says that the technology will allow measurement of water levels with a precision of 3-5 cm, and detailed mapping of vegetation in or near the watercourse.

Another research team, headed by Dr Monica Rivas Casado of Cranfield University, tested the use of drones in hydromorphological river characterisation. Existing methods for identifying hydromorphological features include automated algorithm-based identification from commercially available aerial imagery with resolutions coarser than 10 cm. The research team used the same software applied to drone-captured aerial imagery at resolutions of 2.5 cm, 5 cm and 10 cm, and found that riffles, side bars and submerged vegetation were not accurately identified at resolutions coarser than 5 cm. This implies that high-resolution drone imagery would be more reliable than standard aerial imagery for assessment of the reach.

In South Africa, environmental water requirements (EWR) assessments to determine the ecological Reserve are undertaken at representative cross-sections of the river, called EWR sites, within a river reach designated a management resource unit. At each EWR site, specialists assess the various components of the fauna and flora, as well as habitat integrity, geomorphology and water quality.

"In inaccessible areas, drones could be very useful in finding EWR sites," says Delana Louw, of Rivers for Africa eFlows Consulting. "It would save a lot of time and could also give us a good idea of the characteristics of the upstream and downstream reach from the cross-section. Furthermore, using the drone to take photographs directly above the cross-section would be extremely useful."

Locally, drones could also be particularly helpful in mapping riparian invasive plants, erosion hotspots and pollution point sources, as well as monitoring river restoration and rehabilitation efforts.

Water quality and pollution monitoring

Overseas, drones are being tested for water quality monitoring for ecological research and pollution assessment purposes. In most cases this involves lowering a probe into the water column from a hovering drone, but a team from South Carolina's Clemson University experimented with a hexacopter fitted with flotation attachments so that the drone could land on the water surface. This not only preserved battery life and thus ensured more monitoring points could be included, but also eliminated the need for additional sensors for taking measurements at precise depths.

The more advanced water quality meters available nowadays have probes for measuring temperature, conductivity/salinity, depth, pH and dissolved oxygen, but the traditional (and in some cases more reliable, but very time-consuming) approach is to take boat-based water samples for measuring physical-chemical properties on board or on shore, or even back in the laboratory. Some researchers have used drones equipped with sampling hoses to suck up water for temporary storage in vials on the drone. A limitation of this approach is that only small sample volumes can be collected, which are not as representative of water chemistry as the one-litre samples typically collected during boat-based sampling.

Global engineering firm, Hatch, overcame this limitation by developing a device for deploying a 1.2 litre Niskin bottle from a drone for collecting water samples from flooded pits and tailings ponds at mine sites. Samples have been collected from as deep as 115 metres, and then immediately analysed for pH, iron species and total arsenic using Hatch's mobile water testing lab. This innovation avoids exposing staff to hazards associated with sampling from steep and unstable banks, such as falling, drowning or contact with toxic chemicals.

Many industrial processes discharge heated effluent into natural or manmade waterbodies, and drones can be used to monitor this type of pollution too. Apart from immersing a temperature probe or CTD to obtain a vertical profile through the water column, drones fitted with infrared thermal imaging cameras can be used to gauge the horizontal extent of the effluent plume.

Drone-based monitoring clearly has advantages where boat access is difficult or impossible, with the added benefit that it is unlikely to disturb the upper layers of the water column as much as a boat propeller or oar.

Harmful algal blooms and nuisance weeds

A number of international research groups are exploring the use of drones for monitoring the presence of algal blooms, particularly cyanobacteria, which may be toxic. The French research programme OSS-Cyano, for example, will be presenting progress as part of a session on 'Optical sensors and drone systems for the monitoring of harmful blooms' at this year's International Conference on Harmful Algae (ICHA2018), to be held in France in October.

While South Africa's Earth Observation National Eutrophication Monitoring Programme (EONEMP) website – developed through a WRC-funded project led by Dr Mark Matthews of CyanoLakes – provides a public information service on cyanobacteria blooms in more than 100 of the country's dams and lakes, these waterbodies are all larger than 2 km^2. This is because EONEMP uses data from the Ocean and Land Colour Instrument (OLCI) on the Sentinel-3A satellite, which has a spatial resolution of 300 metres – too large to resolve detail in small waterbodies.

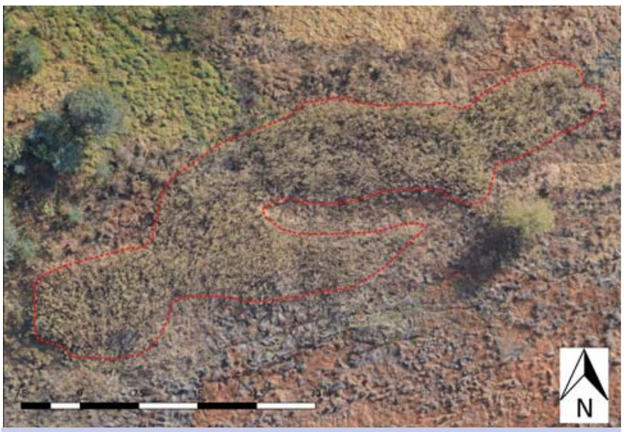
Drones equipped with hyperspectral sensors can overcome this limitation. In fact, ex-South African Dr Deon van der Merwe, now at Kansas State University, found that even relatively cheap, consumer-grade cameras modified to capture near-infrared and blue light wavelengths are useful for detecting cyanobacteria scum on the water surface or along the shoreline. This could provide a first-level assessment of the potential threat to recreational users and to pets, livestock and wildlife that might drink the water.

Drones have also been trialed for mapping the distribution of nuisance filamentous algae like Cladophora and invasive aquatic weeds, such as water hyacinth and salvinia, with some success. Species conservation

Drones have turned out to be less effective for combating poaching as the hype originally suggested, but they are certainly being used for wildlife research and conservation purposes in many parts of the world. Dr Debbie Jewitt, a conservation scientist with Ezemvelo KZN Wildlife, was tasked with investigating the feasibility of using drones for the organisation's scientific services, and reports that important lessons were learned.

"If we fly a drone over an area, take images, come back and download them, and then have to count the target animals manually, it's just too time-consuming – it's better to count them from a plane or helicopter as you fly over," she says. "File sizes can be huge, post-processing is complicated, and we need algorithms to help us identify animals and count them. But software application is where the industry is going to grow a lot going forward."

"We also need to build up a knowledge base on the impact



Marinus Boon/Kite Aerial Imagery

Small pockets of common reed (Phragmites australis) are delineated on an orthophoto generated from done-based photogrammetry

Debbie Jewell/Ezemvelo KZN Wildlife

Drone-based photography is being used by Ezemvelo KZN Wildlife to count roosting yellow-billed storks and pelicans at Ndumo Game Reserve of drone disturbance on different animals, and come up with guidelines so that they can be counted accurately," she adds. "In the meantime, we've been partnering with other people to test how well we can count hippos, crocodiles and bird colonies in wetland habitats. At Amatikulu Nature Reserve, we also visit crocodile nests once the eggs have hatched, the baby crocs have gone into the water and the mother is no longer defending the nest, so that we can count the number of eggshells to get an idea of the laying and hatching success. But it's useful to send a drone over before the time to identify where the active croc nests are. This improves field time because we can go straight there rather than searching the area. It's difficult terrain with dangerous animals, so there's a benefit in terms of safety to staff."

"Drones could also be particularly helpful in mapping riparian invasive plants, erosion hotspots and pollution point sources, as well as monitoring river restoration and rehabilitation efforts."

Other uses

Other water-related applications of drone technology are many and varied. They include checking the structural integrity of dams and bridges, detecting leaks in underground water-supply networks, and locating obstructions in stormwater systems and large sewers. Drones have been used for humanitarian purposes, such as assessing sanitation needs in refugee camps, and for search and rescue efforts during flood disasters. They have even been used to monitor acid mine drainage from abandoned mines and tailings.

The full potential of drones will not be realised in South Africa, however, without some relaxation of the regulations governing their use, particularly with regard to the lengthy and costly licensing, registration and certification process. Fortunately, the Civil Aviation Authority's Executive: Air Safety Operations, Simon Segwabe, indicated in his presentation at DroneCon 2018 in May that the CAA recognises it has a duty to develop the drone industry, and accepts that it needs partners to resolve the challenges.

A stakeholder participation process to review the RPAS regulations has been initiated, and it is likely that a specific operations risk assessment (SORA) approach will be incorporated in future. The approach was one of the main topics discussed at the bi-annual Plenary Meeting of the Joint Authorities for Rulemaking on Unmanned Systems (JARUS), held in Germany in April. JARUS is comprised of representatives of national aviation authorities from 54 countries, including South Africa, working together to recommend a single set of technical, safety and operational requirements for the certification and safe integration of drones. If an achievable solution can be agreed upon, the sky's the limit for drone-based technology, and we can expect to see rapid growth in the development and adoption of water-related applications.

Antoine Lamielle

During floods, drones can be used to plan disaster response efforts and future mitigation measures, search for stranded people and animals, and assess damage to property and infrastructure for insurance purposes.