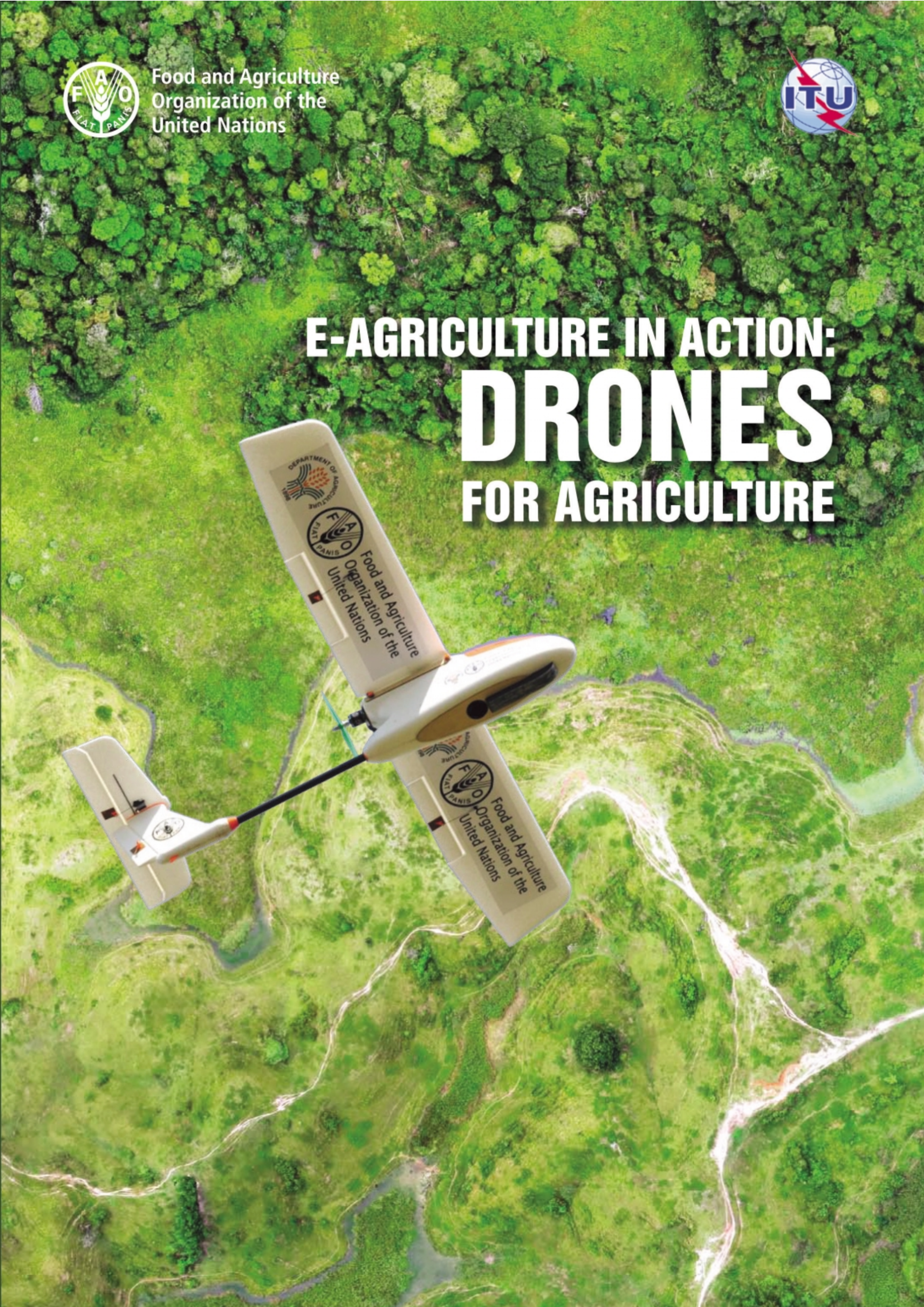
Food and Agriculture Organization of the United Nations

E-AGRICULTURE IN ACTION: DRONES FOR AGRICULTURE



E-AGRICULTURE IN ACTION: DRONES FOR AGRICULTURE

Edited by
Gerard Sylvester

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Preface

Information and communication technologies (ICTs) are playing an increasing role in addressing problems faced by agriculture. The challenges faced by agriculture from climate change alone are enormous and the need for the farming communities to adapt and become resilient is key to feeding the world's growing population. Harnessing the growth and transformative potential of ICTs provides a tremendous platform not only for addressing some of these challenges, but also for accelerating efforts to achieve the Sustainable Development Goals (SDGs) by 2030.

The FAO-ITU *E-agriculture strategy guide* (available at http://www.fao.org/3/a-i5564e.pdf) is actively being used to assist countries in the successful identification, development and implementation of sustainable ICT solutions for agriculture. This framework takes a multi-stakeholder process in developing ICT for agriculture solutions.

The use of unmanned aerial vehicles (UAVs), also known as drones, and connected analytics has great potential to support and address some of the most pressing problems faced by agriculture in terms of access to actionable real-time quality data. Goldman Sachs predicts that the agriculture sector will be the second largest user of drones in the world in the next five years.[1] Sensor networks based on the Internet of things (IoT) are increasingly being used in the agriculture sector to meet the challenge of harvesting meaningful and actionable information from the big data generated by these systems.

This publication is the second in the series titled *E-agriculture in action* (2016), launched by FAO and ITU, and builds on the previous FAO publications that highlight the use of ICT for agriculture such as *Mobile technologies for agriculture and rural development* (2012), *Information and communication technologies for agriculture and rural development* (2013) and *Success stories on information and communication technologies for agriculture and rural development* (2015). The ultimate aim is to promote successful, scalable, sustainable and replicable ICT for agriculture (ICT4Ag) solutions. This publication, *E-agriculture in action: drones for agriculture*, is a step in that direction and is based on a willingness to share knowledge and experiences from various countries and partners.

The chapters in this publication were written by the respective authors and are entirely their own views. We have tried to maintain the original narrative style of each contributor. FAO and ITU do not promote or endorse any of the statements, comments and products mentioned in the chapters. Thus, this is an effort to share knowledge on the use of successful ICTs for agriculture initiatives and we expect that this compilation of case studies will be read in that spirit.

[1] www.goldmansachs.com/our-thinlcing/technology_driving_innovation/drones/


Photo by Skitterphoto from Pexels

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The Informal Experts Group for E-agriculture (IEG4E-ag) (see https://dgroups.org/fao/e-agriculture/ieg4e-ag/) also provided valuable inputs to this publication.

The case studies were documented using an adaptation of the Good Practice Template from the Food and Agriculture Organization of the United Nations (FAO), which is available at www.fao.org/3/a-as547e.pdf

Photo by Ricardo Gomez Angel on Unsplash

Abbreviations, Acronyms and Currency Codes

AGL	Above ground level
ATM	Air traffic management
BVLOS	Beyond visual line of sight
CAA	Civil Aviation Authority
CASA	Civil Aviation Safety Authority
CCA	Climate change adaptation
CNY	China Yuan Renminbi
DRR	Disaster risk reduction
DRM	Disaster risk management
DRRM	Disaster risk reduction and management
EASA	European Aviation Safety Agency
EUR	Euro Member Countries (the Euro)
FAA	Federal Aviation Administration
GPS	Global positioning system(s)
GSD	Ground sampling distance
ICAO	International Civil Aviation Organisation
ICT	Information and communication technology
ICT4Ag	Information and communication technology for agriculture
INR	Indian Rupee
IoT	Internet of things
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
NDVI	Normalized Difference Vegetation Index
PHP	Philippine Peso
RPAS	Remotely piloted aircraft system(s)
SARPs	Standards and recommended practices
UAS	Unmanned aerial system(s)
UAV	Unmanned aerial vehicle
USD	United States Dollar
UTM	Unmanned aircraft (or aerial) systems (UAS) traffic management
VLOS	Visual line of sight
VTOL	Vertical take-off and landing

Not long ago a drone would have only meant a male bee that is the product of an unfertilized egg. Unlike the female worker bee, drones do not have stingers and do not gather nectar and pollen. (Wikipedia)

eBee

An eye in the sky for agriculture: the drone revolution

Photo by kailash kumar from Pexels

Climate change is having a major impact on food security. More than 815 million people are chronically hungry and 64 percent of the chronically hungry are in Asia. The world needs to increase food production by almost 50 percent by 2050 to feed a population of nine billion, yet resources such as land and water are becoming more and scarcer.

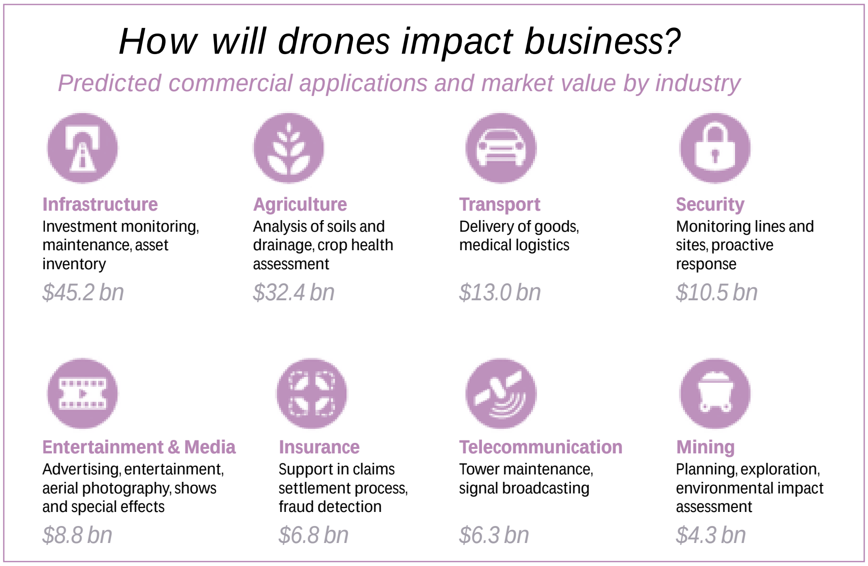
Farming communities and others involved in agriculture have to adapt agriculture to climate change and other challenges. In this context, ICT-driven tools and technologies to enhance decision making through accurate, reliable and timely information have an important role to play. Agriculture has to look towards emerging technologies for solutions to overcome some of the challenges facing it. FAO and ITU, together with partners, have been working together in addressing same of the challenges faced in agriculture through the use of sustainable ICTs.

> "In the current milieu, use of sustainable information and communication technology in agriculture in not an option. It is a necessity."
>
> Gerard Sylvester,
> Food and Agriculture Organization

One of the latest developments is the increase in the use of small, unmanned aerial vehicles (UAVs), commonly known as drones, for agriculture. Drones are remote controlled aircraft with no human pilot on-board. These have a huge potential in agriculture in supporting evidence-based planning and in spatial data collection. Despite some inherent limitations, these tools and technologies can provide valuable data that can then be used to influence policies and decisions.

Drones are used in various fields ranging from the military, humanitarian relief, disaster management to agriculture. A recent PwC report (PwC, 2016) estimates the agriculture drone market to be worth USD 32.4 billion (see Figure 1). The advantages that "an eye in the sky" provides when combined with analytic tools that can interpret the data and images to actionable information have ushered in a new revolution. However, priority in addressing issues related to privacy, safety and security is the key to the sustainable implementation of these technologies.

The United Nations has experimented with drones in various areas of its mandate ranging from humanitarian crises to agriculture. For example, the World Food Programme (WFP) has joined with the Belgian government to deploy drones in humanitarian emergencies (WFP, 2017). The usefulness of drones to facilitate quick data collection with greater accuracy together with providing a safer monitoring system in emergencies was a key element in testing this in the field during challenging humanitarian crises. The United Nations Children's



Source: PwC (2016)

Figure 1. The business of drones

Fund (UNICEF) in partnership with the Government of the Republic of Malawi has set up a humanitarian drone testing corridor (UNICEF, 2017) that would facilitate testing in three main areas – imagery, connectivity and transport. The United Nations High Commissioner for Refugees (UNHCR), also known as the UN Refugee Agency, uses drones to help assess the needs of displaced populations in Africa, especially in the Republic of Mali, the Republic of Niger and the Republic of the South Sudan (UNHCR, 2016). This information is then used to plan assistance including aid delivery. Instances of the use of UAVs by the United Nations Department of Peacekeeping Operations (DPKO), such as in the United Nations Organization Stabilization Mission in the Democratic Republic of the Congo (MONUSCO), are well documented. FAO and Google (FAO, 2016) have partnered to make remote sensing data more efficient and accessible. Access to quality data is the key to making effective policies and interventions towards the achievement of the Sustainable Development Goals by 2030.

The use of drones in agriculture is extending at a brisk pace in crop production, early warning systems, disaster risk reduction, forestry, fisheries, as well as in wildlife conservation, for example.

Crop production: precision farming combines sensor data and imaging with real-time data analytics to improve farm productivity through mapping spatial variability in the field. Data collected through drone sorties provide the much-needed wealth of raw data to activate analytical models for agriculture. In supporting precision farming, drones can do soil health scans, monitor crop health, assist in planning irrigation schedules, apply fertilizers, estimate yield data and provide valuable data for weather analysis. Data collected through drones combined with other data sources and analytic solutions provide actionable information.

> "The adoption of modern technologies in agriculture, such as the use of drones or unmanned aerial vehicles (UAVs) can significantly enhance risk and damage assessments and revolutionize the way we prepare for and respond to disasters that affect the livelihoods of vulnerable farmers and fishers and the country's food security."
>
> José Luis Fernández,
> FAO Representative in the Philippines

Drones such as the DJI Agras MG-1 (DJI, 2017) are designed for precision variable rate application of liquid pesticides, fertilizers and herbicides. Multispectral and hyper-spectral aerial and satellite imagery helps in creating Normalized Difference Vegetation Index (NDVI) maps, which can differentiate soil from grass or forest, detect plants under stress, and differentiate between crops and crop stages. There are strong correlations between crop yield and NDVI data measured at certain crop stages (Huang, Wang, Li, Tian and Pan, 2013). Hence tracking the crop growth at key stages will help to provide an accurate estimate of the crop yield and also to address issues early. Drones fitted with infrared, multispectral and hyperspectral sensors can analyse crop health and soil conditions precisely and accurately. NDVI data, in combination with other indexes such as the Crop-Water Stress Index (CWSI) and the Canopy-Chlorophyll Content Index (CCCI) in agricultural mapping tools can provide valuable insights into crop health. The basic principle of NDVI relies on the fact that leaves reflect a lot of light in the near infrared (NIR). When the plant becomes dehydrated or stressed, the leaves reflect less NIR light, but the same amount in the visible range (Figure 2). Thus, mathematically combining these two signals can help differentiate plant from non-plant and a healthy plant from a sickly plant.

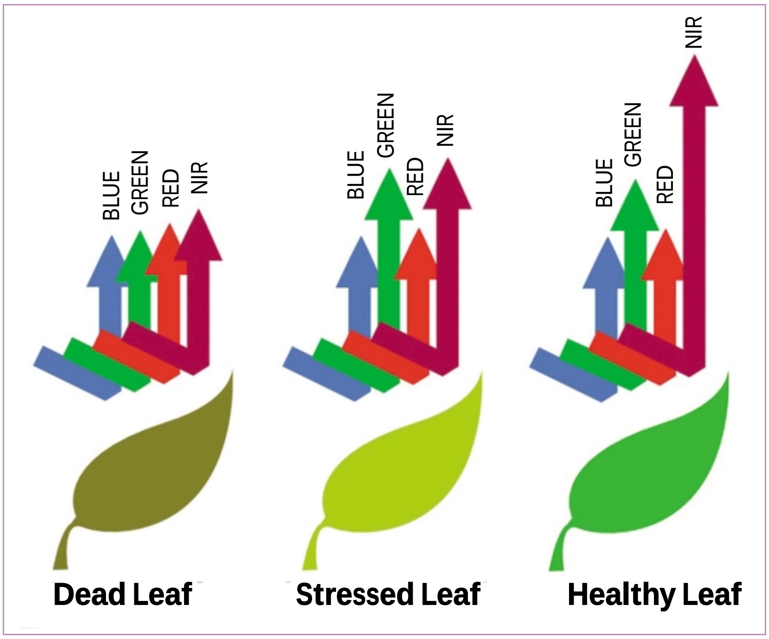


Figure 2. NDVI and plant health

Drones are also increasingly used in the agricultural insurance and assessment sector, including in insurance claims forensics (Wadke, 2017). Drone imagery is very useful in giving an accurate estimate of loss. Companies such as Skymet are using drones to provide agriculture survey services to insurance companies and the state governments of Maharashtra, Gujarat, Rajasthan and Madhya Pradesh in the Republic of India.

Disaster risk reduction: FAO has partnered with national counterparts in developing systems to use drones for data collection that assist in disaster risk reduction (DRR) efforts. These valuable data are then fed into modelling systems with analytics capabilities that then provide valuable insights. Such information can provide rural communities with high-quality reliable advice and can assist the government in better planning disaster relief and response services.

The drones used by FAO in the Republic of the Philippines are equipped with photogrammetric and navigation equipment with a ground resolution of up to three centimetres. This can be programmed to detect details such as NDVI, water stress or lack of specific nutrients in crops. The drone-supporting mapping efforts in the Republic of the Philippines are now being mainstreamed under the FAO's disaster risk reduction and management (DRRM) and climate change adaptation (CCA) strategies.

In the Republic of the Union of Myanmar, FAO is working with the Ministry of Agriculture, Livestock and Irrigation (MOALI) as well as the Myanmar Aerospace Engineering University (MAEU) to utilize modern geospatial technology to enhance disaster preparedness and the response activities of the ministry. This initiative also generates useful information related to upland agricultural risks such as landslides and erosion that could be used to inform agricultural communities and help them understand the risks and reduce the impacts of any disaster. This was piloted in challenging and remote areas such as the Rakhine state and Chin state to scale up community-based DRRM.

Forestry: Open Forests (https://openforests.com/) uses drone-based forest and landscape mapping to provide a new perspective for valuation, monitoring and research. Hundreds of pictures taken by drones are stitched together to large and high resolution orthomaps. These orthomaps can then be integrated into GIS systems and used for analysis, planning and management. Novadrone (Novadrone, 2017) uses drone technology to improve forest management and operational planning, including the monitoring of illegal activities and encroachment. It also assists in collecting various forest metrics such as carbon sequestration, tree canopy analysis, conservation features, tracking native species, monitoring biodiversity and ecological landscape features. Goodbody, Coops, Marshall, Tompalski and Crawford (2017) reported on the successful use of UAVs to update an Enhanced Forest Inventory (EFI) in a small area in interior British Columbia, Canada. The same report also noted the practical advantages of UAS-assisted forest inventories, including adaptive planning, high project customization, and rapid implementation, even under challenging weather conditions. Instances where UAVs were used in conducting an inventory of small forest areas, such as in the Kingdom of Norway (Puliti, Ørka, Gobakken, and Naesset, 2015), led to the conclusion that UAS imagery provides relatively accurate and timely forest inventory information at a local scale.

Fisheries: In the fisheries sectors, the governments of a number of nations including the Republic of Palau, Belize, Jamaica, and the Republic of Costa Rica are now using drones to detect illegal fishing and aid in prosecution of offenders. The government of Belize is using drones to enforce fishing regulations over the Glover's Reef Marine Reserve and other marine protected areas in the waters off Belize (Howard, 2016). Moreover, the use of drones as a fisheries assessment tool by natural resource agencies in Texas and Nebraska in the United States of America has been documented. These agencies have used fixed-wing drones to conduct in-channel habitat mapping during low water in the Guadalupe (Texas) and Niobrara (Nebraska) rivers.

Wildlife conservation: Drones fitted with high definition thermal cameras are also used to track, inspect and monitor livestock remotely. The government of Assam, the Republic of India has partnered with Tata Consulting Services (TCS) to use drones to conduct surveillance, identify unauthorized settlements and to deter poachers in Kaziranga National Park (Muggeridge, 2017) spread over 480 square kilometres. Drones fitted with thermal cameras can identify poachers from their heat signatures even if they are hiding in thick foliage. This effort has proved beneficial for the vulnerable one-horned rhino.

Although drones are an eye in the sky, the real power comes from the strength of data processing and analytics that take place after the data is collected. Solutions such as Smarter Agriculture (Precisionhawk, 2017) offer an integrated platform to use data from drones, sensors and other devices to automate and optimize farm management. Pix4Dag (Pix4D, no date) converts multispectral images into accurate reflectance and index maps, such as NDVI, and uses red, green and blue (RGB) images to generate high-resolution orthomosaics. Sentera's AgVault (Sentera, 2017) handles data that are then used to track crop growth stages, weeds, compaction, storm damage and more. SenseFly's eBee (SenseFly, 2017) provides an integrated solution that includes drones and analytics to support various applications.

There are various classifications of UAVs based on their size – from very small, small, medium to large. Categories such as multirotor models and fixed wing models have their unique characteristics. A fixed-wing aircraft, such as SenseFly's eBee, has the advantage of longer endurance and hence can cover larger areas and has a fast flight speed. The disadvantages are that they need an area for landing and takeoff and are harder to manoeuvre. They can fly at speeds in excess of 80 km/h. This makes fixed-wing UAVs ideal for aerial survey, high-resolution aerial photos, mapping and land surveying. The limitation is in the requirement of a runway to facilitate takeoff and landing. In contrast, multirotor UAVs have lower speed, shorter flight duration and limited payload capacity. Their agile manoeuvring, ability to hover around a particular area, and their ability to operate in confined areas make them ideal for surveillance and for detecting crop pests, diseases and weeds.

> In the Philippines, a country prone to typhoons, aerial drones are taking to the sky to map out at-risk areas of agricultural land to mitigate risk. This innovative practice is also able to quickly assess damages when a disaster strikes.
>
> https://www.youtube.com/watch?v=tBtCVX-j_ek

Near future applications of UAVs are only limited by our imagination. British Telecom is working on prototypes of drones to provide temporary Internet connectivity to challenging locations such as areas that have suffered an earthquake. National Geographic, British Broadcasting Corporation (BBC) and other media groups have begun using drones to film. Companies such as the Israeli startup Flytrex are experimenting with drone delivery services. Although large scale deployment of such autonomous drone delivery systems are mired in various technical, legal and safety concerns, many organizations including Amazon, Walmart, DHL and UPS, are actively experimenting with them. We also see the emergence of interesting innovations such as the drone taxi in Dubai (AsiaNews, 2017) and the Selfly (Selfly, no date), a smart flying mobile phone case that can be used to take selfies!

The global drone regulations database (Global Drone Regulations Database, no date), which has been developed as a multiagency effort provides more in-depth information on drone regulations. The Technical Centre for Agricultural and Rural Cooperation (CTA)-moderated UAV4Ag (Unmanned Aerial Vehicles for Agriculture, no date) is a community of practice on the use of UAVs for agriculture and is a valuable source of information on drones in agriculture.

The next agricultural revolution will be driven by data, which will help to increase agricultural productivity with minimum damage to the environment and increased livelihoods for communities involved in agriculture.

Favourable regulations on the use of small drones for agriculture as well as access to platforms that can aggregate data from various sources to provide valuable insights would be greatly beneficial to farming communities. Supporting ecosystems would facilitate the growth of many innovative start-ups providing agricultural intelligence using drones and other emerging technologies as a service to rural communities. The information gap among rural communities would be addressed by the growth of a new breed of professionals – agricultural infomediaries – who would play a key role in providing hyperlocal actionable information to rural communities by combining various data sources and analytics.

References

AsiaNews. 2017. Drone taxi Dubai [video]. [Cited 22 August 2017]. https://www.youtube.com/watch?v=5Rfe4BFiVNA

DJI. 2017. Agras MG-1 [online]. [Cited 22 August 2017]. https://www.dji.com/mg-1

FAO. 2016. Google and FAO partner to make remote sensing data more efficient and effective. News Article, 1 December [online]. [Cited 23 September 2017]. http://www.fao.org/news/story/en/item/350761/icode/

Global Drones Regulations Database. 2017. Find country [online]. [Cited 22 August 2017. https://www.droneregulations.info/

Goodbody, T.R.H., Coops, N.C., Marshall, P.L., Tompalski, P. & Crawford, P. 2017. Unmanned aerial systems for precision forest inventory purposes: a review and case study. *The Forestry Chronicle*, 93910; 71–81.

Howard, B.C. 2016. Watch how drones fight pirate fishing from the sky. *National Geographic News*, 28 December [online]. [Cited 21 September 2017]. https://news.nationalgeographic.com/2016/12/drones-fight-pirate-fishing-belize-conservation/

Huang, J., Wang, X., Li, X., Tian, H. & Pan, Z. 2017. Remotely sensed rice yield prediction using multi-temporal NDVI data derived from NOAA's-AVHRR. *PLoS ONE*, 8(8): e70816 [online]. [Cited 22 September 2017]. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3742684/

Muggeridge, P. 2017. Saving the endangered one-horned rhino, one drone at a time. *#DigitalEmpowers*, 8 January [online]. Tata Consultancy Services. [Cited 21 September 2017]. http://digitalempowers.com/saving-endangered-one-horned-rhino-one-drone-time/

Novadrone. 2017. Drone forestry [online]. [Cited 22 August 2017]. https://novadrone.com/en/applications/drone-for-forestry/

Pix4D. 2017. Aerial crop analysis [online]. [Cited 22 August 2017]. https://pix4d.com/product/pix4dag/

Precisionhawk. 2017. Smarter agriculture [online]. [Cited 23 August 2017]. http://www.precisionhawk.com/agriculture

Puliti, S., Ørka, H.O., Gobakken, T. & Naesset, E. 2015. Inventory of small forest areas using an unmanned aerial system. *Remote Sens*, 7(8): 9632–9654 [online]. Doi: 10.3390/rs70809632 [Cited 22 September 2017]. http://www.mdpi.com/2072-4292/7/8/9632

PwC. 2016. *Clarity from above: PwC global report on the commercial applications of drone technology*. May [online]. [Cited 21 September 2017]. https://www.pwc.pl/pl/pdf/clarity-from-above-pwc.pdf

Selfly. Unleash your camera [online]. [Cited 22 August 2017]. https://www.selfly.camera/

SenseFly. 2017. eBee the professional mapping drone [online]. [Cited 23 August 2017]. https://www.sensefly.com/drones/ebee.html

Sentera. 2017. Agvault unlocks your data [online]. [Cited 22 August 2017]. https://sentera.com/agvault-software/

UNHCR. 2016. UNHCR uses drones to help displaced populations in Africa. News and stories, 21 November [online]. [Cited 22 September 2017]. http://www.unhcr.org/news/latest/2016/11/582dc6d24/unhcr-uses-drones-help-displaced-populations-africa.html

UNICEF. 2017. Africa's first humanitarian drone testing corridor launched in Malawi by government and UNICEF. Press release, 29 June [online]. [Cited on 22 August 2017]. https://www.unicef.org/media/media_96560.html

Unmanned aerial vehicles (UAV) for agriculture. 2017. Unmanned aerial vehicles (UAV) for agriculture [online]. [Cited 22 August 2017]. www.uav4ag.org

Wadke, R. 2017. Insurers now employing drones to check claims by farmers. *The Hindu-Business Line*, 14 March [online] [Cited 22 September 2017]. http://www.thehindubusinessline.com/economy/agri-business/insurers-now-using-deploy-drones-to-check-claims-by-farmers/article9583909.ece

World Food Programme. 2017. WFP and Belgium start efforts to deploy drones in humanitarian emergencies. News, 3 February [online]. [Cited 29 August 2017]. https://www.wfp.org/news/news-release/wfp-and-belgium-start-efforts-deploy-drones-humanitarian-emergencies

For more information

Gerard Sylvester
Regional Knowledge and Information Management Officer
Food and Agriculture Organization of the United Nations (FAO)
Regional Office for Asia and the Pacific
gerard.sylvester@fao.org


Photo by Harald_Landsrath on Pixabay

Case study

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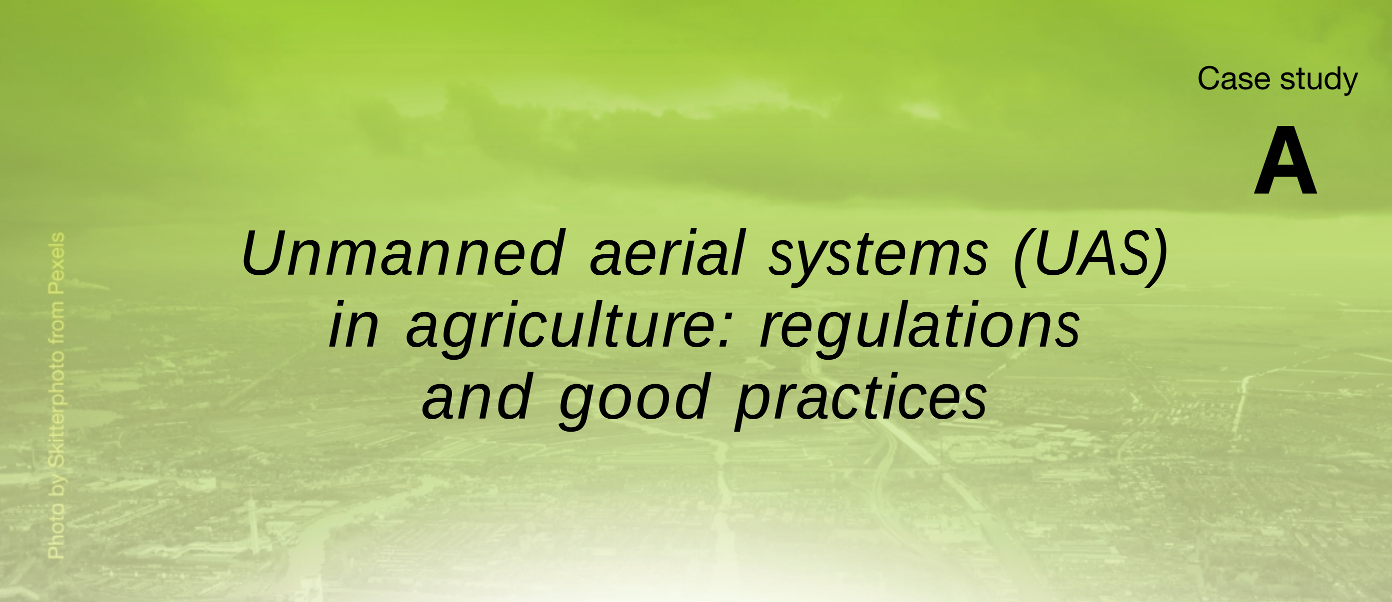


Photo by Skitterphoto from Pexels

Unmanned aerial systems (UAS) in agriculture: regulations and good practices

Introduction

In 2017 a situational irony played out in southern Africa as the “fall armyworm” devastated more than 100 000 hectares of maize in Zambia. The Zambian Air Force was directed to assist the Ministry of Agriculture and Disaster Management and used aircraft to target the pests through the aerial application of pesticides at several “hot spots” throughout the country (African Aerospace Online News Service, 2017).

Funding and support was also required to contain proximate infestations of red locusts across southern Africa, again using aircraft. Three outlying airstrips were established in the United Republic of Tanzania to manage areas of severe locust outbreak and both fixed and rotary wing aircraft were utilized. Helicopters are preferred because of their retarded speeds, easier access to marshy areas, and as their downwash can lift locusts from roosts. Aircraft are expensive to fly or hire and local hindrances are numerous. In this scenario the only fixed wing aircraft available was lost in a tragic accident and helicopter maintenance had to be carried out some distance away in the Republic of South Africa. Would regulations allow UAVs to augment these efforts?

National early warning systems and more specifically agricultural entrepreneurs have always needed accurate and up-to-date information on the extent and status of the resources they monitor and depend on. Agricultural aircraft have been in use for this purpose since the 1920s. Remote sensed data from satellites have been used increasingly to assess crop distribution, extent and health from the sky. Over the last few years unmanned aerial vehicles (UAVs) or drones have become one of the world’s most talked about technologies, used by people in a wide range of professions, including surveyors, agronomists, infrastructure inspectors, and humanitarian aid workers to name a few.

Although UAVs are unlikely to entirely replace manned aircraft or satellites, they have a number of advantages over these more traditional remote-sensing methods. The technology is capable of collecting very high-resolution imagery below the cloud level, with much more detail than the satellite imagery usually available to developing country analysts. They are easy to use: most drone mapping and data-collection missions are now conducted autonomously, meaning that the UAV essentially flies itself. Moreover, data processing applications are becoming less expensive and easier to use.

When it comes to early warning systems, UAVs could enhance the present practices in locating outbreaks, monitoring plague development and movement (Cressman, 2016), and in the localized control of early stage plague outbreaks.

The use of UAVs to monitor poaching of endangered species, or illegal or unsustainable uses of forest resources and land occupancy in general, has started in many parts of the world. International and national non-governmental organizations have promoted the technology to support indigenous peoples in gathering evidence of undesired activities within their ancestral territories.

UAVs can be used in livestock management and fisheries, in surveying, land tenure and land use planning, humanitarian and emergency relief, stockpile estimation, crop damage assessment, scientific research, inspection of fixed and mobile assets, real estate and tourism marketing, media production, small cargo delivery, and more.

What therefore are the barriers to the rapid deployment and uptake of the technology in some countries? What aviation regulations apply to conventional aviation operations at present? How do these differ for missions conducted by UAVs?

There are concerns from government authorities on the improper use of this disruptive technology: privacy infringements, invasion of reserved airspace and potential aircraft collisions, personal injury and property damage.

Unmanned aircraft

Small UAVs are unmistakably different from aircraft in so many ways yet they are considered as full-fledged aircraft in most countries. This is perhaps the prime challenge impacting their governance. Few understood how the UAV industry could reinvent itself so dramatically and become so far reaching in every enterprise and field of work. The number of UAVs now flying is mind-boggling and this will surely increase exponentially. According to Vogt (2017) the yearly sales of small UAVs have reached 400 000 units in the Federal Republic of Germany in 2016 and are likely to reach 1 million in 2020. In the United States of America, according to a global information provider (The NPD Group, 2017), United States dollar sales of drones more than doubled in the 12 months ending February 2017, with a 117 percent increase each year.

The technology is considered by many as equivalent to the mobile phone revolution, i.e. game-changing and disruptive. Nevertheless, in November 2016, Violeta Bulc, the European Union (EU) Commissioner for Transport (European Commission, 2016) stated:

> Drone technologies are a unique opportunity for the EU economy to generate additional growth and prosperity: they open the door to new markets for innovative services with immense potential.

In 2016 the African Union Commission (NEPAD, 2016) appointed a High Level Panel on Emerging Technologies to provide evidence-based analyses and recommendations that could inform policy direction at the continental, regional and national level on the utilization of existing and emerging technologies. Precision agriculture, artificial intelligence and UAV technology are among the technologies under consideration.

Many urban areas including airports and helicopter landing sites and their associated approach/departure paths need to be safe from the interference of flying objects. Aviation is not without risk and the reputation of UAV technology would be severely affected in the aftermath of a mid-air collision with a passenger aircraft. Increasingly, UAVs are equipped with geo-fencing software that prevents them from flying within restricted areas or warns the pilot if they enter a sensitive no-fly zones. Automatic updates with temporary flight restrictions around wildfires help protect authorized fire fighting aircraft and ensure fire crews can operate without disruption. Software such as the Geospatial Environment Online includes permanent flight restrictions around prisons, nuclear power plants and other sensitive locations, as well as temporary restrictions for large stadium gatherings and national security events. It also introduces flexibility for drone pilots by giving them the ability to unlock some restricted areas where they have permission to operate (DJI, 2016). Nevertheless, unscrupulous users may disable such controls or use UAVs that are not equipped with similar security features. A.J. Emmerson, former and often critical member of the Australian Civil Aviation Authority (CAA), notes there is no place in aviation safety regulations for cost–benefit analysis and that "the objective of ensuring safety of flight cannot be left to enterprising but unregulated operators or to a doctrine of survival of the fittest (Emmerson, no date, p. 6)."

Nevertheless there is a balance required between public safety and reliable commerce, a trade-off between over-regulation and promoting private enterprise. There are pieces of airspace where UAVs could conduct unfettered operations at low risk and there are areas where access will never be appropriate with our present technical know-how.

Important definitions and nomenclature

Various nomenclatures are used in reference to unmanned aircraft. The public and media often use "drone". The term unmanned aerial vehicle (UAV) refers to the unmanned aircraft. The term unmanned aerial system (UAS) denotes the larger system of the airborne portion of the UAV, the pilot located elsewhere controlling the aircraft via a ground control station through wireless linkages (control and command links) plus the sensor(s) mounted on the UAV and the software that may be used to analyse the data gathered by the sensor(s). A UAV can be operated manually, or programmed to operate automatically or to be fully autonomous.

UAVs are often dissimilar to conventional aircraft and are obtainable in a range of shapes, sizes, and configurations. The take-off mass of a UAV has been used historically to classify the devices. Frequently used categorizations occur at 2 kg mass, at 25 kg and at 150 kg. The category a UAV is assigned to will influence the minimum age of the pilot, the expected remote pilot competence, whether the device has to be registered with the CAA or not, the need for electronic identification and installed geo-fencing software. UAVs heavier than 150 kg are generally considered the equivalent of conventional aircraft with obligations to meet analogous airworthiness and certification standards.

The main configurations of UAVs are fixed wing aircraft or vertical take-off and landing rotary wing platforms such as helicopters or multicopters. Fixed-wing UAVs require an approach and landing runway and are usually flown in automated mode. Copters are easier to pilot manually, need limited space to take off and land but have a shorter flight endurance. Hybrids in the form of vertical take-off and landing (VTOL) systems are more versatile operationally as they maintain efficient range without the need for a runway.

Safety and a shift towards a risk-based approach

Present conventional aviation flights are conducted either under visual flight rules – where the pilot on board remains in visual contact with the surrounding environment and the flight is made clear of other aircraft and obstacles; or under instrument flight rules – where aircraft can be flown through cloud or poor visibility, for example at night. These categories are regulated and do not easily transfer to the operations of UAVs. The vast majority of such operations thus far are flown within sight of the pilot. Experience has developed common operational good practices that reduce the ground and airborne safety risk. These practices are becoming widespread, apply to small UAVs only, and are termed Visual Line of Sight (VLOS) operations. In this scenario, the UAV flies within a 500 m horizontal radius around the remote pilot while remaining below 120 m above ground level (AGL). The UAV must respect a no-fly zone of several kilometres or more from conventional (piloted) airports and helipads and must otherwise always give way to conventionally piloted aircraft. UAVs must also avoid other UAVs. Flight containment can be defined through instructing the UAV to return to its base or setting three-dimensional flight limitations (maximum distance from control point plus maximum altitude) and performance limitations (e.g. maximum speed). This mitigates the risks of a loss of control. UAVs are usually not allowed to fly over gatherings of people and critical infrastructure. These restrictions vary between countries.

There is however a constant appetite to fly missions unrestrained by VLOS. Beyond Vusual Line of Site (BVLS) operations involve flight outside of the pilot’s locale. Impediments to this expansion include the need to extend the command and control of the aircraft and the payload communications links. It also necessitates “detect or sense and avoid” technology as an alternative to the pilot’s ability to monitor the airspace visually for risks while operating the aircraft safely clear of people and obstacles.

Discounting whether regulatory authorities should allow BVLOS or not, the operator must remain sufficiently clear of other airspace users, and people or infrastructure on the ground so as to avoid a safety hazard. BVLOS missions have occurred, either contained in airspace restricted from other users or integrated within the airspace system with approval from the relevant authorities. A recent example is the Zanzibar Mapping Initiative funded by the World Bank and implemented by Drone Adventures, the State University of Zanzibar and the Commission of Lands (Guermazi, 2016).

Safety risk in aviation has hitherto focused on the overall risk to the air traffic management (ATM) system and is especially attentive to fatalities or injuries to persons on board the aircraft. As safety management for UAV operations evolves, the glaring difference is there is no one on board a UAV and therefore this hazard is nil, although the level of risk to those on the ground may have increased. This latter alteration certainly originates from the proximity of UAV operations to people in both vertical and horizontal terms, and the number of flights. It is conceivable that this change to the risk picture also relates to the standards of design, production, operation and maintenance of UAVs, which are often lower than for conventional aircraft. It is arguable that these issues heighten the level of risk to other airspace users especially low-level operations such as gliders, emergency services flights, or military.

Data protection laws vary among countries and even across states. Privacy is one of the principal barriers to UAV operations as legal institutions assess peoples' rights around this new technology. Approval for operations is often predicated on proof that rights will not be violated. Cyber security is also regulated. The risk of hacking an UAV and using it for dangerous exploits exists and Global Positioning System or control links can be jammed causing loss of control of the UAV. Insurance and liability issues need to be addressed prior to requests for flights. Finally, dropping items from UAVs is illegal in many countries, and spraying from drones and the carriage of dangerous goods is highly regulated or prohibited.

The European Remotely Piloted Aircraft System (RPAS) Steering Group and the Drone Advisory Committee in the United States of America are strong steering groups that have influenced the acceptance of a risk-based approach to the integration of UAVs into the airspace system. An early adopter of a risk-based approach is the Swiss Federal Office of Civil Aviation through its application process for operational approval of UAV flights. The Joint Authorities for Rulemaking on Unmanned Systems (JARUS), an international technical group delivering mature UAV guidance for authorities to use in rulemaking efforts, has promoted this approach. This was the first formalized process to be widely accepted. The European Aviation Safety Agency (EASA) is progressively introducing regulatory changes adopting a risk-based approach to UAV integration. Additionally, EASA will regulate all European member states for UAVs under 150 kg removing this previous division of responsibility between national CAAs and the European Commission.

The European strategy ensures that UAVs will be treated as a new type of aircraft with proportionate rules based on evaluation of the risk associated with each operation and that their operators are responsible for their use. A clear need for continued advancement in technologies and standards is recognized and public acceptance is a key to growth (EASA, 2017). In order to increase awareness on the need for responsible use of UAVs for both recreational and professional purposes, the European Commission is supporting the establishment of a multilingual online data repository for European rules and regulations (European Commission, no date)

Risk increases progressively according to the size of the UAV, the complexity of the operation (BVLOS, night-time), the location (remote, urban, high capacity airspace) and is balanced by a range of mitigating circumstances. The EASA three-tiered approach begins at the low risk end with the "open" category constrained to low-altitude VLOS, away from crowds and infrastructure and below 25 kg. As risk increases, an operational risk assessment of each operation must be conducted, and this is assessed by the NAA or a qualified entity for approval under the "specific" category. This group might include flights at higher altitudes or BVLOS, near urban areas, or with heavier UAVs. As the operation becomes more like a conventionally piloted flight, the mission must be treated as such and moves into the "certified" category with a regulatory regime mirroring that of manned aviation. Australia has followed EASA's risk approach and tiered categorization and the country moved ahead with its amended regulations in 2016.

The risk-based approach addresses the most difficult challenge: the expectation that UAVs must meet equivalent levels of safety as applied to conventionally piloted aircraft, while integrating into the present ATM structure in a seamless manner, being transparent to air traffic control and not penalizing other airspace users. The objective of target levels of safety in conventional aviation is to reduce risk through mitigation or prevention to protect the crew and/or passengers on board. All risk must be reduced to an acceptable level that is as low as reasonably practicable.

Airspace and its regulatory framework

The significance of the Conference on International Civil Aviation in Chicago in 1944 should not be understated. Notably, it produced the Convention on International Civil Aviation containing recommendations on airworthiness and air traffic control and a bilateral arrangements framework that has been used widely. The Convention has been published in English, French, Russian, Spanish, Arabic and Chinese language editions. The Conference led to the establishment of the International Civil Aviation Organization (ICAO) as the agency tasked with preparing aviation standards and recommended practices (SARPs) at the global level. ICAO is a specialized agency of the United Nations and is responsible for the coordination and regulation of international air travel. Each member state of ICAO has a responsibility to enact basic aviation law to allow for the development and promulgation of civil aviation rules, regulations and requirements, consistent with the provisions of the Convention's Annexes (ICAO, 2016). States can choose either a stringent or passive regulatory approach in regulatory implementation. The effective implementation of these responsibilities ensures continued safe international aviation operations.

ICAO member states and unmanned aircraft regulations

Of ICAO's 191 member states, only 30 countries with current state regulations are listed in its online UAS toolkit (ICAO, no date). It is noteworthy that, except for the Federative Republic of Brazil, the links offered by ICAO include only developed countries. Many other online depositories provide information on national UAV regulations. Locating, collecting, translating and summarizing UAV regulations is an enormous undertaking. Because of the magnitude of the task, available information can be obsolete or out of alignment with actual legislation. This challenge exposes the lack of standardization and interoperability for those wanting to operate UAV missions. It becomes a barrier when consideration is given to the large number of countries either banning civilian UAV operations or where there is a dearth of regulations.

Much like the industry and its activities, the legislative framework surrounding aviation is complex. The following is a summary of the Australian civil aviation legislation to illustrate the convolutions. Australian legislation is divided into primary legislation – laws passed by parliament (e.g. the Civil Aviation Act and the Airspace Act) and delegated or subordinate legislation – legislative instruments under the Act signed by an official empowered by the

Act. Delegated legislation includes airspace, civil aviation and civil aviation safety regulations. These are the first two tiers. The third tier comprises a range of manuals and instruments to assist users in complying with the rule set. This framework allows the Australian Civil Aviation Safety Authority (CASA) to respond quickly to technological changes and safety concerns, to balance safety with economic reality and to provide legal certainty.

Australia was the first country to publish UAV regulations – its Civil Aviation Act. CASA, recognizing that consistent legislation would allow integration, developed Civil Aviation Safety Regulations Part 101 in 2002, which consolidated the rules governing all unmanned aeronautical activities into a single body of legislation. Even with an adaptable regulatory framework, it took over a decade for Australia to update its rule set. Part 101 was amended in 2016 to acknowledge a low-risk class in UAV operations and establishes a suite of standard operating conditions permitting reduced regulatory requirements. Also, landowners can now fly commercial operations over their own property as long as they abide by these conditions – significant for VLOS agricultural uses. Other changes simplified the approval process and allowed for more complex operations to be dealt with under the third tier of regulation that can be quickly adapted to necessary transformations as UAV technology and industries using it evolve.

Other regulatory bodies and issues

The proposed changes to the basic European aviation regulations include annexes addressing privacy, data protection, liability, insurance, security and environmental protection. For example, UAVs must be built and operated to be as quiet as possible, and designed to minimize emissions.

Operators should be aware of the surrounding ecosystems and any regulations to protect them. Animals do react to UAV operations and sensitive areas such as breeding or feeding grounds and migratory routes must be avoided. The United Republic of Tanzania provides an excellent example whereby UAV operations are not allowed in the national parks for security reasons.

Conventionally piloted aircraft in agriculture

Aircraft have been used in agricultural for over a century. The obvious advantages of aerial agriculture come from an aircraft's ability to cover large areas quickly without damaging the growing environment. This is important because a quick response to disease and pests is often imperative.

Although more expensive and complex, helicopters have better performance at slow speeds and became an alternative to fixed wing aircraft. They are especially suited to small, irregular fields bordered with obstacles or if the runway is too distant or non-existent. An added benefit of helicopter spraying is the spread of chemicals on the underside of leaves from rotor wash. Aircraft administer a fifth of today's applied crop protection (National Agricultural Aviation Association, no date).

Using aircraft to locate and muster livestock is known as aerial mustering. Culling of pests or herds and protection from poaching can also be carried out more efficiently and cost effectively with aircraft. Operations are generally below 500 feet in harsh or remote areas and therefore pose additional risks that are difficult to eliminate.

Regulation of agricultural aviation activities has not gone far enough in reducing accidents. The National Transportation Safety Board reports that 81 fatalities transpired from 802 accidents in agricultural aviation in the decade ending 2010 (NTSB, 2014, p. 8). Agricultural aircraft come under the Code of Federal Regulations Part 137 in the United States of America, in which many rules are altered. For example, such aircraft are restricted from operating over congested areas (Federal Aviation Authority, 2014). A reduction in harm during accidents would occur in sorties where UAVs replaced aircraft. A similar, regulatory approach could also be taken where UAS agricultural operations could be afforded more leniency.

Unmanned aircraft in agriculture

Potentials and challenges

UAS offer a range of exciting opportunities for improving the management of crops, livestock, fisheries, forests and other natural resources. At the most basic level, UAS permit farmers to obtain a birds-eye-view of their crops, allowing them to detect subtle changes that cannot be readily identified by “crop scouts” at ground level. UAVs equipped with special sensors can collect multispectral images that are stitched to generate spectral reflectance bands. These bands allow users to calculate indexes such as a Normalized Difference Vegetation Index (NDVI), a Leaf Area Index (LAI) or a Photochemical Reflectance Index (PRI), allowing farmers to view crop changes or stress conditions that are otherwise invisible to the human eye.

NDVI provides information about the different biomass levels within a land parcel. Interpreted NDVI images can tell a lot about water stress or excess, nutrient deficiencies, pest infestations, crop diseases, or other conditions affecting crop development. Imagery indicators, such as NDVI, represent a first layer of information that can be built upon through field visits or a dedicated algorithm. Such algorithms are already available for fertilization where imagery indicators are translated into agronomic indicators to guide fertilizer inputs.

These remote sensed data can also be used to speed up the painstaking process of conducting crop inventories and yield estimates. Ranchers and fishery managers are beginning to experiment with the technology, hoping to take advantage of the ability of UAVs to cut down on the time and expense of conducting patrols and reconnaissance work. Cattle ranchers, with a large area of land to cover, have used UAVs to determine the location of their livestock, and some have found UAVs useful for conducting regular surveys of fencing (Greenwood, 2016).

In Africa, there are growing efforts to increase farmers’ opportunities to access credit. The provision of detailed and up-to-date spatially-defined farm data on location, size, standing crops and their health and biomass can help improve farmers’ creditworthiness.

UAS technology has also been used to document illegal land and resource use. With UAS-gathered imagery of illegal logging and land occupancy, government agencies can prioritize and speed up their inspection efforts, ensuring that a week-long field inspection will collect enough evidence to justify government intervention. In addition, UAVs create openings for ICT entrepreneurs supporting the agriculture sector. This is especially true among younger people who are eager to embrace cutting-edge technologies and establish businesses based on them.

Notwithstanding the great opportunities offered by UAVs for inducing dramatic changes to the agricultural production systems in developing countries, the presence of too restrictive, or even disabling rules and regulations governing the import and use of UAVs can hinder the development of a very promising industry, which could attract and engage educated youth in rural areas. In fact, some countries have resorted to a complete ban on the import and use of UAVs.

Impact of regulations on large to small UAVs – some cases studies

(a) Hawaii: large UAS used on coffee plantations

In 2002 a joint research project between NASA, the New Mexico State University and AeroVironment, Inc. and in cooperation with the Kauai Coffee Company explored the benefits and challenges associated with a larger UAV integrated into the air traffic management system. The image collection platform used was the lightweight, solar-powered, flying wing Pathfinder-Plus (see Figure A1). Its on-station mission loitered on-site at 21 000 feet (6.4 km) for four hours. Remote pilots based over 25 km away on the ground at Barking Sands airport used real time imaging from on-board cameras to position the Pathfinder-Plus clear of areas obstructed by cloud for the footage. Lower altitude flights would have avoided the majority of the cloud cover.

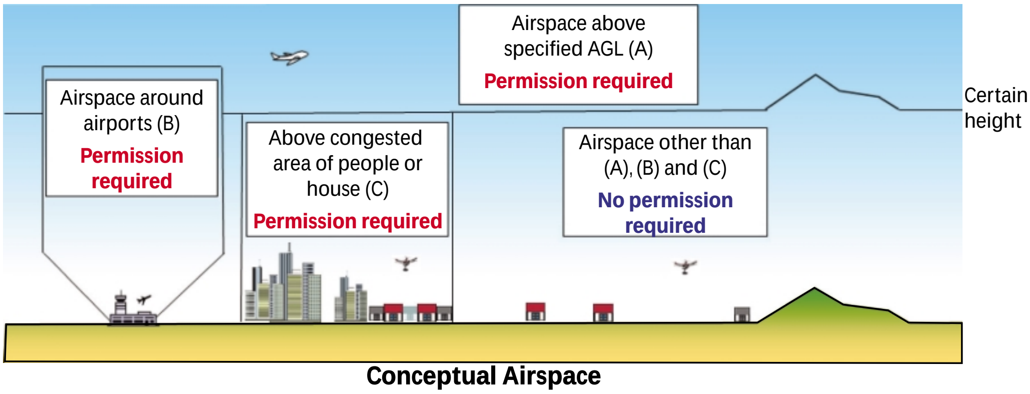
Figure A1. The Pathfinder-Plus remotely flown above Hawaii

© NASA

The UAV operated in the National Airspace System as if it was a conventional aircraft and was equipped with a transponder for electronic visibility to other aircraft and for the Honolulu air traffic controllers monitoring the flight. The trials were conducted with a Federal Aviation Administration (FAA) Certificate of Authorization after months of planning and with several teams comprising dozens of experts. This project shows how UAVs are beneficial in agriculture but only within a regulatory framework supporting safe operations (Herwitz, Johnson, Dunagan, Higgings, and Sullivan, 2004).

(b) Japan and the United States of America: a medium UAV used on vineyards

The Yamaha RMAX from Japan is a remote controlled helicopter with over two million flight hours in agricultural spraying and weighs 94 kg. Numerous 2 500 RMAX platforms operate in Japan where more than 2.5 million acres are treated annually. The helicopter's flight time can reach one hour supporting VLOS agricultural missions conducted 20 m above the crops to replace or augment the application of chemicals from backpack spraying among tightly spaced vine rows on challenging terrain. It navigates via a precision GPS, decelerating quickly during a failure and slowing to descend onto the field in an emergency. New Japanese regulations were published in December 2015 (see Figure A2).



Source: Ministry of Land, Infrastructure, Transport and Tourism (2015)

Figure A2. Depiction of Japanese UAV airspace rule set

Permission from the Minister of Land, Infrastructure, Transport and Tourism is only required for operations more than 150 m above ground level (AGL), near airports or above densely inhabited districts. Otherwise, operations must occur in daytime, VLOS, clear of events where people gather and more than 30 m from people or property on the ground. Transporting hazardous materials and dropping from UAVs is not allowed without permission (Ministry of Land, Infrastructure, Transport and Tourism, 2015). Crop dusting is still big business in Japan.

There are moves to utilize this platform in the United States of America. Yamaha received a Part 137 certification for agricultural aircraft operations in the United States of America in late 2015 allowing the RMAX to be operated subject to state and local authority approval. In 2013 it received a permit allowing remote spraying. The conditions of this authorization allow operations only over specific agricultural areas, not to exceed 7 m AGL, at least five miles from any airports and with a 48-hour pre-flight notification to the FAA.

Although VLOS operations have potential for small plots, many farms in the United States of America do not have small plots. Multiple VLOS operations could cover the necessary ground and complex imagery stitching could provide required mapping, although this is expensive and not necessarily real time data (Komissarov, 2016). BVLOS operations would be advantageous and need special approval. However, only a limited number have been conducted in the United States of America outside of restricted airspace (Stöcker, Bennett, Nex, Gerke, and Zevenbergen, 2017).

(c) The Republic of South Africa: a small UAV for vineyards

In the Republic of South Africa in 2014, flight trials were conducted using a small UAV to ascertain the value of imagery in detecting vine plant health before and after the application of organic nutrition. Mapping flights were conducted and the nutrients were applied using conventional methods immediately afterwards. High-resolution farm and vine mapping imagery was taken before the crops were sprayed with nutrients and at stages afterwards. This data was shared with farmers, agronomists and soil scientists. The imagery shows improvement in the treated rows relative to untreated rows (Figure A3).

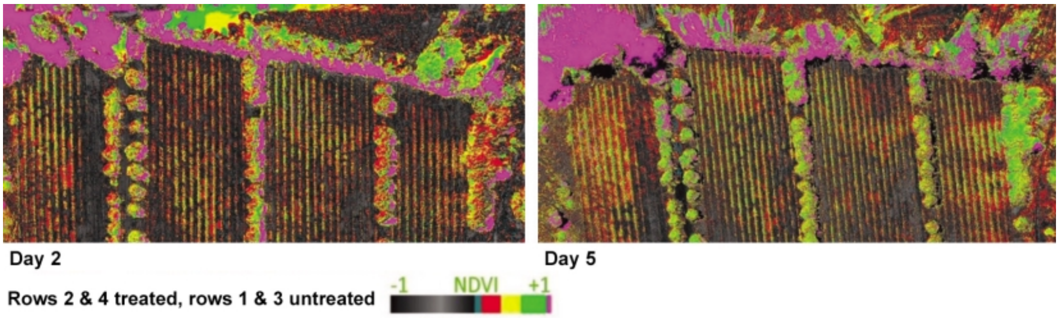


Figure A3. UAV before and after imagery highlighting nutrient value

© CTA

New regulations for operating UAVs in the Republic of South Africa became effective in July 2015. These enforce a long list of requirements that take time to complete and are reported as expensive and overly onerous (Wijnberg, 2017). For example, the licensing rules to operate UAVs commercially require a pilot licence, air services licence from the Department of Transport, a letter of approval for each UAV and a remote operators certificate based on an approved operations manual (Mortimer, 2017).

(d) The Republic of India: a small UAV on a coffee plantation

In 2016 a small UAV was used to survey land use in a coffee plantation. The results provided the landowner with exact area measurements of land utilization to determine the exact area under a coffee plantation to estimate yields.

This process would have been very costly and time consuming employing ground based surveyors as the estate was located in a mountainous region with no road access at many points. UAVs are popular in the Republic of India, however there is no clear set of regulations as yet.

In April 2016, the civilian airspace regulatory authority, the Director General of Civil Aviation, published draft “Guidelines for Obtaining Unique Identification Number and Operation of Civil Unmanned Aircraft System” (Director General of Civil Aviation, 2016). Under these draft rules, each UAV must be issued and fitted with a unique identification. A UAS operator permit and insurance is required for all civil UAV operations at or above 120 m AGL in uncontrolled airspace (Global Drone Regulations Database, no date).

The experience gained from these trials illustrates that UAV requirements have not been a hindrance and that operations are mostly low-level and away from cities with many private properties. Operations have been conducted over a private property in a city and all necessary permissions from the local police were issued. Land ownership in the Republic of India tends toward smaller areas of land and even though such surveys are reported as technically positive, they are not yet economically viable. Future operations are planned over large areas of land under contract farming by multinational food companies. Concern has been raised that the benefits from UAV use will decline in the Republic of India as multiple states may regulate UAV activity through a patchwork of rules. It is crucial that the federal government reviews present inconsistent rule making and publishes consistent regulations to support growth and industry innovation (India, 2017).

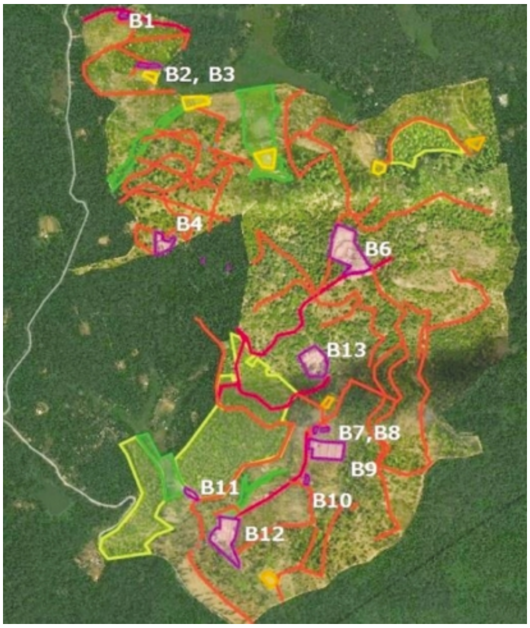


Figure A4. Land use survey imagery from UAV showing buildings and access roads

UAV rules and regulations in Africa

The **Republic of South Africa** was the first country to implement and enforce a comprehensive set of legally binding rules governing UAVs in July 2015. As shown in Table A1, a total of 15 countries has published dedicated UAV regulations as of the writing of this paper. These represent 28 percent of the total number of countries on the continent. Seven countries, listed in under "minor references", appended early ICAO guidance to their aviation regulations. It is noteworthy that the guidance is entirely replicated suggesting standardization has already been a factor in Africa.

Table A1. Status of UAV regulations by country in Africa

Status	Countries
Regulations are in place	Botswana, Cameroon, Gabon, Ghana, Madagascar, Mauritius, Namibia, Nigeria, Rwanda, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.
Minor references are included in aviation regulations	Benin, Burkina Faso, Chad, Côte d'Ivoire, Mali, Mauritania and Senegal.
Regulations are pending or being developed	Angola, Kenya and Malawi.

Sources: Jeanneret and Rambaldi (2016) updated by Soesilo, Meier, Lessard-Fontaine, Du Plessis, and Stuhlberger (2016) and Guerin (2017)

The African Civil Aviation Commission represents 54 African states and was created in 1964 by ICAO but it remains autonomous. This organization could be a conduit for the evolution of consistent regulations across Africa, recognizing that ICAO remains fixed only on creating SARPs pertinent to large UAVs, or those deemed by EASA in the "certified" category.

The fact that the Republic of South Africa has regulations in place, is seen by some as posing serious challenges to the development of a thriving UAV service industry. According to a licensed UAV operator (Wijnberg, 2017), the Republic of South Africa has arguably the most restrictive regulations in the world for commercial use. The heavy handed approach has forced UAV companies to operate illegally locally or to move out of the country to stay in business, or close shop entirely, with or cease operating. In the Republic of South Africa the regulations consider that using an UAV for data-generation in agriculture means that it is used commercially and should be governed in the same manner as commercial manned aircraft. This requires the operator to comply with a number of major steps, including, but not limited to the following:

- obtaining a remote pilot license (RPL);
- registering the aircraft;
- obtaining an air service license (ASL) from the Department of Transport (DoT); and
- obtaining a remote operator's certificate (ROC) from the South African Civil Aviation Authority (SACAA).

Single business owners find it difficult to comply with the regulations as they require a large number of positions to be filled, such as quality assurance manager, flight operations manager, safety officer and security officer. The total cost to comply with the regulations amounts to over ZAR 500 000 (EUR 32 600) and takes over two years to complete. Often, some sections such as the Air Services License will expire and require renewal before the ROC is issued.

Since the regulations were published in 2015, only 14 companies have been licensed to operate and there is a backlog of over 400 applications (Wijnberg, 2017).

The Republic of Uganda has no regulations in place and UAVs are confiscated from travellers at the airport of Entebbe. Those attempting to obtain an import permit for running UAS services for agriculture have to deal with a range of government bodies including the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Ministry of Internal Affairs, Ministry of Defence, Civil Aviation Authority and more, without having the certitude of obtaining the necessary permits.

The Civil Aviation Authority in the **Republic of Kenya** announced the development of its national regulations governing the use of remotely piloted aircrafts in February 2017. As of the writing of this chapter, such regulations have still to be enacted and the import and use of UAVs is prohibited. Several development agencies and international research institutions interested in supporting the introduction and use of UAVs in the agricultural domain are facing a legal void and have put projects on hold or cancelled allocated funding.

The Civil Aviation Authority of the **Republic of Rwanda** enacted its UAS regulations in June 2016 and has issued only one permit to a local company so far.

The Civil Aviation Authority of the **Republic of Ghana** enacted its regulations in June 2016. In December 2016 it issued an additional directive instructing all UAV operators or users to obtain written permission from regional or local police stations before operating UAVs. The enabling environment favoured the industry and a number of UAV operators already service the agricultural sector.

As a parameter of reference, in the **United Kingdom of Great Britain and Northern Ireland**, the legislation governing the use of UAVs is still being fine-tuned after a public consultation that took place in 2016 and is meant to be enacted under the Vehicle Technology and Aviation Bill (Butcher and Haylen, 2017). Nonetheless, as of 17 July 2017 there were a total of 3 046 approved Small Unmanned Aircraft (SUA) operators deploying sub-7 kg UAVs and/or 7 to 20 kg UAVs (Civil Aviation Authority (UK), 2017).

Conclusions: the impact of regulations on UAS in agriculture

The world is dealing with the emergence of new technologies in the position to gather data at an impressive level of detail. In this respect, governments have been busy legislating on personal data management and privacy issues. Civil UAV technology, for professional and recreational use, adds a layer of complexity as its deployment allows access to views previously inaccessible to many, and impinges on airspace, a dimension traditionally used by manned aircraft. UAS offer a vast range of service opportunities. According to PwC, UAS will transform agriculture into a high-tech industry for the first time, with decisions being based on real gathering and processing of data and a likely increase in productivity and yields (Drone Powered Solutions, 2016). Being a new technology and developing faster than the regulations intended to regulate its use, it is quite challenging to assess how these have influenced UAS operations in agriculture. In addition, a range of stakeholders usually contributes to the development of such regulations.

In shaping their governance, there is the need to find a balance between managing the ground and air risks of UAS operations, the need for safety and privacy and the benefits to agriculture and broader natural resource management. Hence it is of paramount importance that CAAs closely interact with stakeholders in the agricultural sector in the process.

Networking and sharing are key ingredients, which could lead to the identification of best practices. There is a clear move away from classifying different operations based on the weight of the UAV and toward the risk of the operation. Light, VLOS low altitude operations should not impinge on the regulatory authorities or require them to be accountable. The governments can then dedicate their energies on assessing the riskier operations and on education campaigns so that operators and the public understand the rule set under which they exist. They can also focus on addressing gaps in the legal framework (for example privacy and data issues) and examining the relationship between new technologies and automation and the ATM system (Stöcker, Bennett, Nex, Gerke, and Zevenbergen, 2017). The EASA three-category approach is clearly the world's best practice and its spread around the globe should be supported for national and international harmony and common standards. All steps to streamline the regulatory process should be taken.

The common thread in regulation requirements around the globe are that UAVs should be registered and insured and their operators should have a licence, with the exception of harmless flights, i.e. very small, platforms away from people.

There is the need to continue advocating for the standardizing of regulations toward a risk-based approach, especially as this will clearly benefit agriculture. A special focus is needed on addressing data capture and privacy issues as these are the backbone of agricultural improvements.

UAS services represent a new frontier in technology development. Youth is attracted by technology, its development and use. UAS for agriculture could be a magnet for educated youth in developing countries to develop service enterprises based or at least operating in rural areas, thus generating jobs opportunities and improving agricultural production and farmers' returns on investment. As the industry is fast developing in countries where the regulations are enabling, and on hold or winding down where these are too strict, expensive to comply with or disabling, regulators should be fully aware that the impact of their decisions reaches far beyond security and privacy and could determine whether agriculture becomes a data-driven and profitable enterprise or not.

References

African Aerospace Online News Service. 2017. *Going into battle against the deadly hoards* [online]. [Cited 7 July 2017]. http://www.africanaerospace.aero/going-into-battle-against-the-deadly-hoards

African Civil Aviation Commission. n.d. *African Civil Aviation Commission* [online]. [Cited 16 July 2017]. www.afcac.org

Butcher, A., & Haylen, L. 2017. *Civilian drones*. London, House of Commons Library.

Civil Aviation Authority (UK). 2017, July 14. *Small unmanned aircraft (SUA) operators holding a valid CAA permission* [online]. [Cited 30 July 2017]. https://publicapps.caa.co.uk/docs/33/20170714 RptUAVcurrent.pdf

Cressman, K. 2016, April. Preventing the spread of desert locust swarms. *ICT Update*, pp. 8-9.

Director General of Civil Aviation. 2016. *Guidelines for obtaining unique identification number (UIN) & operation of civil unmanned aircraft systems (UAS)* [online]. [Cited 19 July 2017]. https://goo.gl/vjM7EV

DJI. 2016. *DJI GO app now includes GEO geofencing system* [online]. [Cited 21 July 2017]. https://goo.gl/gDoF1x

Drone Powered Solutions. 2016. *Clarity from above. PwC global report on the commercial applications of drone technology*. Warsaw, PwC.

Drones University. 2017. *SACAA crackdown on illegal drone usage* [online]. [Cited 21 July 2017]. http://www.drones.university/sacaa-crack-illegal-drone-usage-doubles-sa/

EASA. 2017. *EASA and you, civil drones* [online]. [Cited 21 July 2017]. https://www.easa.europa.eu/easa-and-you/civil-drones-rpas

Emmerson, A. no date. *Why we regulate the way we regulate and who pays* [online]. [Cited 21 July 2017]. https://infrastructure.gov.au/aviation/asrr/submissions/files/250_a_emmerson_8_feb_2014.pdf

European Commission. 2016. *Drones: Commissioner Bulc presents plans for a drones services market* [online]. [Cited 14 August 2017]. https://ec.europa.eu/transport/modes/air/news/2016-11-23-drones-commissioner-bulc-presents-plans-creation-european-drone-services_en

European Commission. no date. DroneRules.eu [online]. [Cited 12 August 2017]. www.dronerules.eu

Federal Aviation Authority. 2014. *FAA part 137* [online]. [Cited 7 July 2017]. https://goo.gl/iRdGLb

Global Drone Regulations Database. no date. [online]. [Cited 17 August 2017]. https://www.droneregulations.info/India/IN.html#country-search

Greenwood, S. 2016, April. Drones on the horizon: new frontier in agricultural innovation. *ICT Update*, pp. 2-3.

Guerin, D. 2017. Global drone regulations database [online]. [Cited 22 July 2017]. www.dronregulations.info

Guermazi, B. 2016, September 11. *Watching Tanzania leapfrog the digital divide* [online]. [Cited 21 July 2017]. https://goo.gl/ALxTKd

Herwitz, R. S., Johnson, L. F., Dunagan, S. E., Higgings, R. G., & Sullivan, D. V. 2004. Imaging from an unmanned aerial vehicle: agricultural surveillance and decision support. *Computers and Electronics in Agriculture*, pp. 49–61 (also available at *http://www.afcac.org/en/index.php?option=com_content&view=article&id=2&Itemid=69*).

ICAO. no date. *Current state regulations* [online]. [Cited 21 July 2017]. https://goo.gl/AZsG3v

ICAO. 2016. *Safety oversight manual, part A: the establishment and management of a state's safety. Doc. 9734*. Montreal: ICAO.

India, C. 2017. *Civilian drones and India's regulatory response* [online]. https://goo.gl/vq16lo

Jeanneret, C., & Rambaldi, G. 2016. *Drone governance: a scan of policies, laws and regulations governing the use of unmanned aerial vehicles (UAVs) in 79 countries.* Waheningen, CTA.

Komissarov, V. 2016. *Drones in agriculture: hype or reality* [online]. [Cited 21 July 2017]. https://medium.com/@V.K.Komissarov/drones-in-agriculture-hype-or-reality-33b333c12376

Ministry of Land, Infrastructure, Transport and Tourism. 2015. *Description of unmanned aircraft regulation in Japan* [online]. [Cited 19 July 2017]. https://www.mlit.go.jp/en/koku/uas.html

Mortimer, G. 2017. *South Africa's constrained commercial drone industry* [online]. [Cited 21 July 2017]. https://www.suasnews.com/2017/02/south-africas-constrained-commercial-drone-industry/

National Agricultural Aviation Association. no date. *Industry facts about the aerial application industry* [online]. [Cited 21 July 2017]. www.agaviation.org

NEPAD. 2016. *African Union Commission appoints High Level African Panel on Emerging Technologies* [online]. [Cited 21 July 2017]. https://goo.gl/wUbG9s

NPD Group. 2017. *Premium drones drive steady sales, while lower cost drones fly off shelves during the holidays* [online]. [Cited 21 July 2027]. https://goo.gl/WwQF6P

NTSB, N. S. 2014. *Special investigation report on the safety of agricultural aircraft operations.* Washington, NTSB.

Soesilo, D., Meier, P., Lessard-Fontaine, A., Du Plessis, J., & Stuhlberger, C. 2016. *Drones for humanitarian and environmental applications: a guide to the use of airborne systems in humanitarian crises.* Geneva, FSD.

Stöcker, C., Bennett, R., Nex, F., Gerke, M., & Zevenbergen, J. 2017. Review of the current state of UAV regulations. *Remote Sensing*, Vol 9 (5). Doi: 10.3390/rs9050459

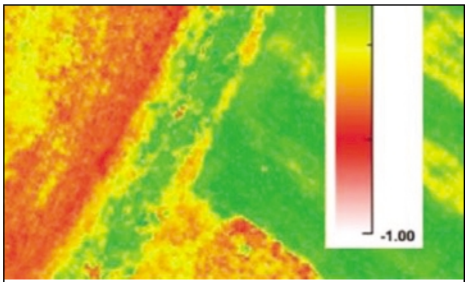
Vogt, T. 2017. UTM exploration: testing mobile connectivity for integrating UAS. RPAS 2017 and European RPAS Policy, Regulatory & Innovation Forum, 13-14 June, Brussels.

Wijnberg, L. 2017. Are South African regulations stifling the drone-based agri-service industry, a potential game changer for agriculture? [online]. [Cited 22 July 2017] http://www.cta.int/en/article/2017-08-08/are-south-african-regulations-stifling-the-drone-based-agri-service-industry-a-potential-game-changer-for-agriculture.html

For more information

Giacomo Rambaldi
CTA, Senior Programme Coordinator ICTs
rambaldi@cta.int

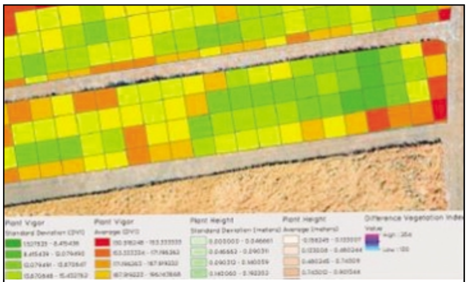
David Guerin, for CTA
ozyrpas@gmail.com



Advanced Plant Health Indices

Assess canopy variation in biomass or detect plant stress in mid-to-late growth stages

3-Band Sensor



Assess Field Performance

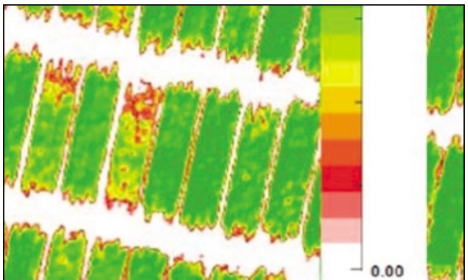
Quality plot-level statistics on plant count, height, vigour, leaf area, and canopy cover

5-Band Sensor

Field Water Ponding Mapping

Identify and measure areas that cannot be used for growing because of standing water

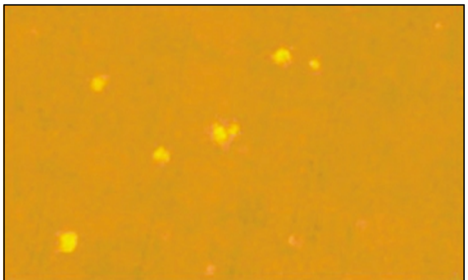
5-Band Sensor



Measure Nitrogen Content in Wheat

Gain insight into heat stress, water use, and plant metabolism

5-Band Sensor



Weed Pressure Mapping

Protect crop production through the detection and assessment of invasive weed species

5-Band Sensor

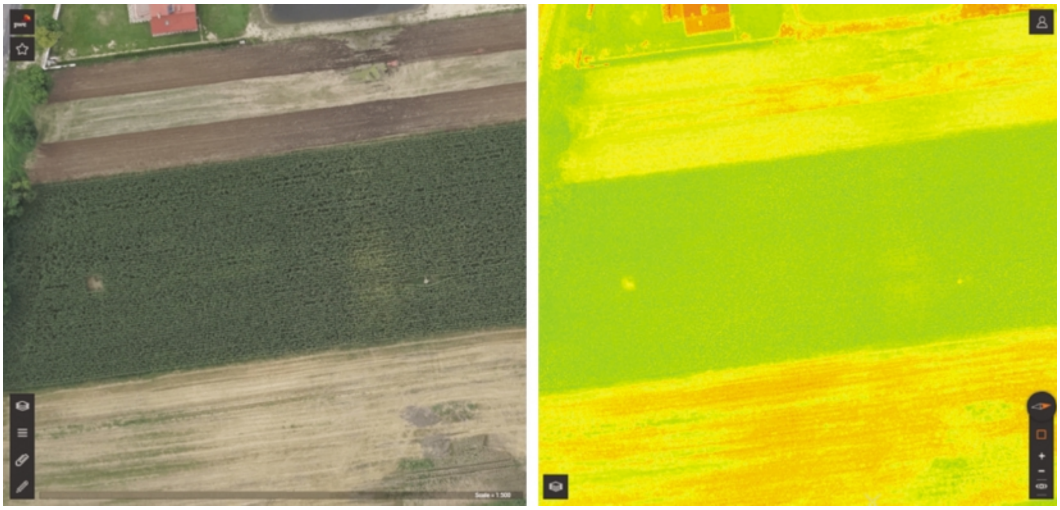
Sensors that can be mounted onto drones to support a diverse range of applications (www.precisionhawk.com)

Drone technology as a tool for improving agricultural productivity

PERSPECTIVES FROM PwC's DRONE POWERED SOLUTIONS CENTRE OF EXCELLENCE

Technology has transformative potential for virtually every aspect of our existence. It improves efficiency by reducing workload and required time in numerous industries. The agriculture industry is no exception. The progressive automation of agricultural processes has significantly improved the productivity of agriculture labour, shifting masses of workers into other productive industrial areas. Since then, scientific advances in chemistry, genetics, robotics and many other applied sciences have fuelled the accelerated development of agricultural technology. In effect, in recent years agricultural production has increased substantially. However, the demand for agricultural products is due to rise even further with estimations of aggregate agricultural consumption to increase by 69 percent from 2010 to 2050, mostly fuelled by an increase in global population from 7 to 9 billion people during the same time frame. The only feasible answer for this urgent call for increased agricultural production must come from technology sector. Drone technology and advanced image data analytics with the capabilities it provides have the potential to become important parts of the technology mix that could fill the gap. Between current agricultural production and the needs of the future.

There are a number of applications of drone technology convergence with advanced image data analytics that can be utilized in the agriculture industry. Our recent estimations valued the addressable market for drone application in agriculture at USD 32.4 billion. The majority of applications is based of drones as a mobile, aerial platform for advanced image data acquisition. Based on particular project requirements drones can be equipped with a range of image data sensors. The most established application based on drone-acquired image data is to assess the health of crop vegetation. An unmanned airborne platform equipped with infrared cameras can enable the development of Normalized Difference Vegetation Index (NDVI). The NDVI-view of a certain area enables the analysis of the intensity of solar radiation absorption and therefore the condition of the monitored plants. This method has been widely used for decades based on satellite- or plane-borne cameras, but the resolution of the resulting products has been insufficient to map fields, precisely, not to mention specific plants. Drone technology as a platform for image data acquisition has brought the NDVI mapping capabilities to a completely new level of accuracy making it possible to monitor the condition of not only plants, but also specific parts of plants. This level of information enables the early identification of early identification of pests, diseases and pests. The precisely mapped and identified issues within a certain area can be addressed with precise applications of fertilizers, pesticides or herbicides. Advanced geospatial NDVI products can also be used in case of natural disasters or destruction of crops to precisely estimate the



Source: PwC commercial drone consulting project

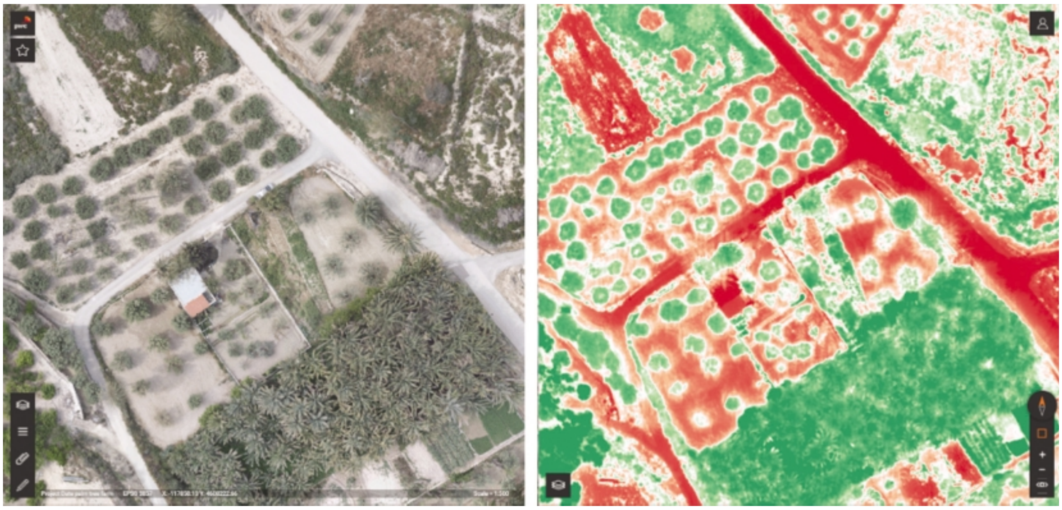
Figure B1. Analysis of the NDVI index output enables monitoring of corn crops condition

level of losses by comparing the pre-disaster state of vegetation with the damages that occurred. Precise documentation of damages followed by precise estimation of reduction in estimated yields can be used in insurance procedures.

Nowadays, drone technology is more and more often employed in insurance, with agriculture claims management being one of the key applications. Another, rather non-obvious application of drone imaging and mapping capabilities is counting and taking stock of herds of animals. With the application of high resolution infrared cameras, every single animal is a separate heat mark enabling counting with an accuracy higher than using conventional methods. The development of applications of infrared cameras in herds monitoring allows even more sophisticated tasks. Focusing on a single animal with a high-resolution infrared camera enables assessment of its health based on a temperature comparison, allowing swift identification and treatment of ill animals.

Another application of drone technology in agriculture is crop spraying. The technology was first implemented in Japan in the 1980s when unmanned helicopters equipped with spraying equipment and pesticides tanks were used to spray crop fields. Typical modern day spraying drones have tank capacity of over ten litres of liquid pesticide with discharge rate of over a litre a minute, allowing them to cover a hectare in ten minutes. However, to leverage drone technology fully as a spraying platform, the spraying needs to be paired and synchronized with the above-mentioned imaging, processing and automated analytics capabilities in order to address the affected areas or plants with precision. Such an approach would lead not only to the improvement of dosage in the affected areas, but also to a reduction in the overall use of chemicals within the area.

Mapping and imaging capabilities of drone platforms with a range of sensors can be used throughout the whole production process in order to plan production better and therefore



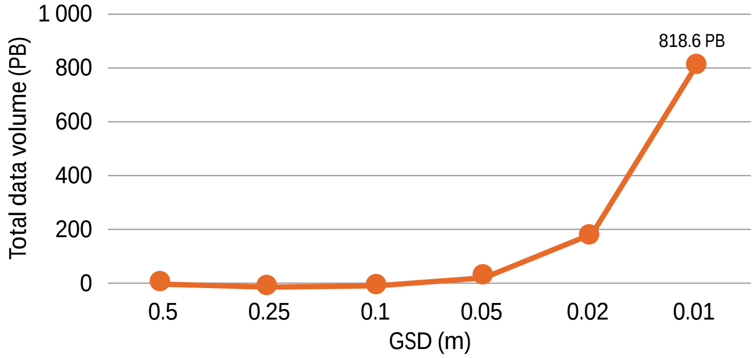
Source: PwC commercial drone consulting project

Figure B2. Application of NDVI index products enables monitoring of date palms health and identify separate palms potentially infected by pests

improve productivity. Before the vegetation cycle starts, drone technology can be used to assess soil condition and thus potential yields. The key application in assessing soil condition is actual 3D mapping of the terrain with precise soil colour coverage. This helps to assess the soil quality as well as the moisture and water flow precisely. Throughout the vegetation period, cyclical flights can be employed to monitor crops and the agriculture process in order to plan operations and swiftly react if issues are observed. This can instantly be done by automated drones equipped with spraying capabilities. Drone-enabled NDVI index values analysis products help to indicate the precise timing for harvesting. The fusion of advanced aerial information acquired with the help of drones with data from other sources such as weather forecasts and soil maps can help to refine the final information and enable the farmer to take full advantage of the farm and maximize the yields to their natural limits. What is even more important for specific farms in the Asia-Pacific region, is that the drones enable difficult to access and remote areas such as terrace rice fields or fruit plantations in mountainous regions to be reached.

The drone technology sector as well as image data processing and analytics are all in a constant state of change and development. There is a range of technologies in the development pipeline that can potentially transform the sector in the coming years. This would most likely lead to the immediate development of new uses in the agriculture industry or strengthening the impact of UAV technology in existing ones. One of the leading examples is the rapid development in the field of machine learning and deep learning. Automation of cognitive capabilities with image data shifts the processing and analytics from humans to trained algorithms. This fact could ultimately lead to machines making decisions on which plants require moisturizing, treatment with pesticides, are ready to harvest, or alternatively which animal should be treated with antibiotics to prevent the spread of disease among the herd. The convergence of the drone as a platform for various sensors with machine learning-based intelligent processing and analysis software would develop a virtually infinite range of possibilities, maximizing the production and limiting the manned workload even further. This would in effect lead to an increase in productivity and a decrease in the price of agricultural products, thus enabling the gap between current production and the needs of the growing global population to be closed.

However, the use of advanced image data analytics and processing pose a challenge in the fields of a data strategy and data management. One of the key challenges related to data management is the fact that along with accuracy and precision of information, the size of datasets grows accordingly generating up to 140 GB of data for a single square kilometre with ground sampling distance (GSD) of 1 centimetre. To address this challenge, data strategy tailored to specific requirements is necessary. Another key challenge is incorporating drone-borne imaging and advanced image data processing and analytics into existing agricultural processes in order to ensure the agriculture sector can fully leverage new information. The possession of additional knowledge and analytics tools will not bring benefits on its own. The implementation and integration of the new information into agricultural business processes is required to truly tap the potential of drone solutions and advanced image data analytics in the industry.



Source: Food and Agriculture Organization of the United Nations agricultural land area for 2014

Figure A3. Estimated total data volume for Asia and Oceania agricultural land geospatial products, depending on their Ground Sampling Distance (Petabytes = 10^{15} bytes)

Drone technology and advanced image data analytics tools are of great potential for the agriculture industry. Drone solutions can be implemented in a range of applications throughout the whole process from precise mapping for planning purposes, assessing the condition of crops and plants, to precise crop spraying. But with as all other tools, the right strategy and setup is required to fully leverage the technology available. With the booming industry of drone technology and sensors, and the availability of image data processing and analytics tools, the technology mix for the required solutions must be planned cautiously to maximize the benefits while optimizing the costs. The same is true for the process of data acquisition itself. Along with operating drone solutions, a large volume of data is generated. Therefore the requirements regarding precision, resolution and layers of data employed must fully reflect the requirements of any specific use and thus should be planned on a project basis. Lastly, once the optimal solution is developed and the data acquired does not exceed processing capabilities, the information extracted needs to be fully implemented and integrated into the business process. However, once the required technology mix is deployed, the analytical capabilities are optimized and the solution is fully integrated into business processes, the full potential of the technology is ready to be exploited and the productivity improved substantially. Maximizing yields and limiting the workload and thus the costs of goods will be vitally important in the ensuing decades of unprecedented growth of agricultural product demand that we face globally and particularly in the Asia-Pacific region.

For more information

Adam Wisniewski
PwC, Director of the Drone Powered Solutions Centre of Excellence
adam.wisniewski@pwc.com

Photo by CM29breizh on Pixabay

Case study

C

Mapping and monitoring rice areas using remote sensing, crop modelling and information and communication technology (ICT)

EXPERIENCES FROM THE INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI)

Introduction

Rice has been a prime focus for the development of integrated remote sensing and information and communications technology (ICT) based monitoring, mapping and yield estimation systems in South Asian and Southeast Asian countries in order to target food security, which is closely connected to the livelihoods of smallholder farmers. In 2012, the International Rice Research Institute (IRRI) together with a private partner, sarmap, initiated a project titled “Remote Sensing Based Information and Insurance for Crops in Emerging Economies (RIICE)”. The project was funded by the Swiss Agency for Development and Cooperation (SDC) and was a public-private partnership aiming to reduce the vulnerability of smallholder farmers engaged in rice production. The geographic extent of Phase-I (2012–2015) of this project spans six target countries located in South Asia and Southeast Asia, namely the Kingdom of Cambodia, the Republic of India, the Republic of Indonesia, the Republic of the Philippines, the Kingdom of Thailand and the Socialist Republic of Viet Nam (Figure C1).

In Phase-II (2015–2017) area coverage in the Kingdom of Cambodia, the Kingdom of Thailand, the Socialist Republic of Viet Nam, and Tamil Nadu, the Republic of India was expanded. In 2014, a new entity “Philippines Rice Information System (PRISM)” was initiated and funded by the Department of Agriculture, the Republic of Philippines which will continue until the end of 2017. RIICE Phase-III activities will continue in the Kingdom of Thailand, the Kingdom of Cambodia, the Socialist Republic of Viet Nam, the Republic of India and the Republic of Indonesia from 2017 to 2019.

These satellite-based rice monitoring (SRM) initiatives integrated remote sensing, crop modelling and ICT tools to generate and provide near-real time and accurate information on rice growth, yield, as well as damage caused by abiotic and biotic stresses. The RIICE technology is capable of providing accurate and timely village level information about rice planted areas, including information on the start of the season and its variability with geography, expected and actual yield and the impact of any disaster on specific rice growing areas. RIICE is now providing accurate and almost real time information for the implementation of crop insurance programmes in various countries (i.e. the Republic of India

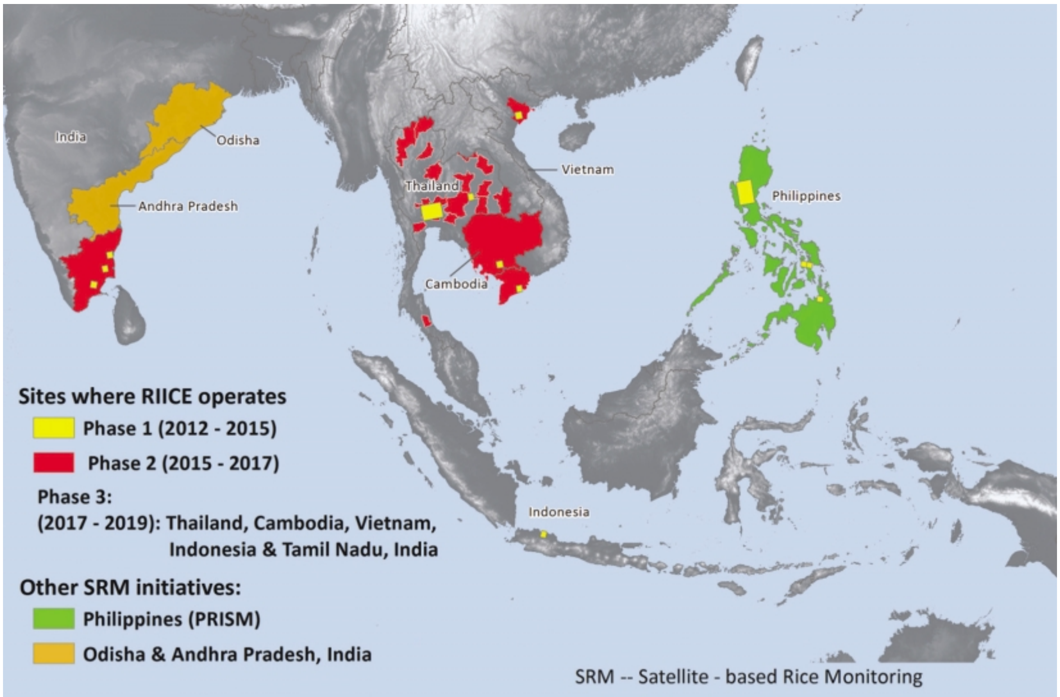


Figure C1. Satellite-based rice monitoring (SRM) sites in South Asia and Southeast Asia

and the Socialist Republic of Viet Nam). These projects have already made significant impacts in terms of rice monitoring, mapping and forecasting. This integrated system combining remote sensing, crop modelling, web geographic information system (GIS), smartphone, unmanned aerial vehicles (UAV), and Amazon Web Services (AWS) has generated promising results in all countries. With greater than 85 percent accuracy, more than 24.5 million hectares of rice have been monitored in 2016, a significant increase of area coverage of 1.6 million ha when the initiative started in 2012. Partnership and agreement with national and state governments have also been established on the use of the RIICE technology for food security and crop insurance policies with substantial investment has been received from states governments in the Republic of India and the Republic of Philippines.

The SRM initiative focused principally on the development of sustainable technologies and thus in that context both projects were fully committed to developing in-country capacity building and integration of a developed rice monitoring system within the national system. This rice monitoring system helps the government and other rice sector actors by providing accurate and up to date information that allows for better management of domestic rice production and distribution hence resulting in reduced vulnerability of smallholder farmers and increased food security. The generated information can also help governments and rice value chain actors to identify and manage any risks involved in rice production better. Accurate and almost real time information on rice growth can help governments and other actors to adapt their economic policies on rice import and export and can also enable disaster response and preparedness agencies to better anticipate and coordinate relief efforts in the event of natural calamities. High quality data generated through the RIICE technology can also be used to develop more efficient and transparent crop insurance products to protect smallholder farmers.

The main beneficiaries of this practice are the national research and extension system in the target country/state, central and local government units, insurance providers, researchers, scientists and policymakers.

These projects already demonstrate good practice for satellite-based rice crop area monitoring and mapping and are a promising practice for UAV-based rice crop health monitoring. Integrated remote sensing and ICTs were applied in agronomy. ICTs were used with earth observation processing software, integrated remote-sensing and crop modelling interface, ORYZA crop growth model, Geo-Open Data Kit (Geo-ODK), climate data retrieval and processing module. These practices were implemented in the Republic of the Philippines (whole country), the Socialist Republic of Viet Nam (Mekong Delta and Red River Delta), the Kingdom of Cambodia (whole country), the Kingdom of Thailand (North, North East, and Central Plain), the Republic of India (Tamil Nadu and Odisha states), the Republic of Indonesia (Subang district, West Java and Purbalinga district, Central Java).

Various public and private partners were involved and played specific roles. Partners in this study include: SDC (RIICE project donor); sarmap (earth observation processing technology provider); German Development Agency (GIZ) (country governance and crop insurance implementation); Alliance (crop insurance implementation), Swiss Re Group (crop insurance implementation); Philippines Rice Research Institute (PhilRice) (ground information collection and dissemination and recipient of technology transfer); Philippines Department of Agriculture (PRISM project donor, ground information provider, IT management entity, and recipient of technology transfer); Cambodia Agriculture Research and Development Institute (CARDI) (ground information collection and dissemination and collaborator on capacity building); Department of Planning and Statistics (DPS), Ministry of Agriculture, Forestry and Fisheries (MAFF), Kingdom of Cambodia (ground information collection and dissemination, IT management, and recipient of technology transfer); Thailand Rice Department (ground information collection and dissemination, IT management, and recipient of technology transfer); Thailand Geo-Informatics and Space Technology Development Agency (GISTDA) (IT management); Thailand Department of Agricultural Extension (DOAE) (ground information collection and dissemination and recipient of technology transfer); Tamil Nadu Agricultural University (TNAU), Republic of India (ground information collection and dissemination, IT management, and recipient of technology transfer); Indonesian Center for Agricultural Land Resource Research and Development (ICALRD) (ground information collection and dissemination and recipient of technology transfer); State Department of Odisha, Republic of India.

Methodology and development of ICT

The satellite-based rice monitoring system deploys three software modules, namely MAPscape-Rice (Nelson *et al*., 2014), Rice Yield Estimation System (Rice-YES) (Setiyono *et al*., 2017), and ORYZA Crop Growth Model (Li *et al*., 2017) This was done by developing

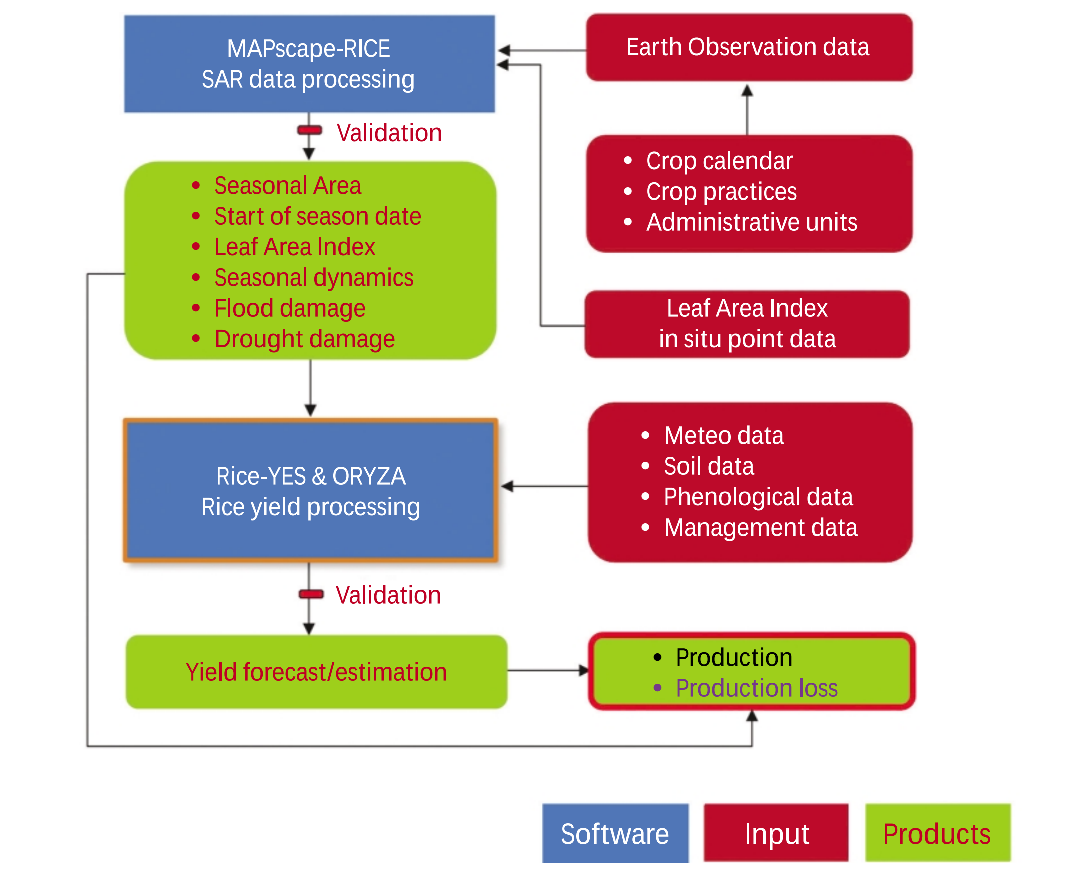
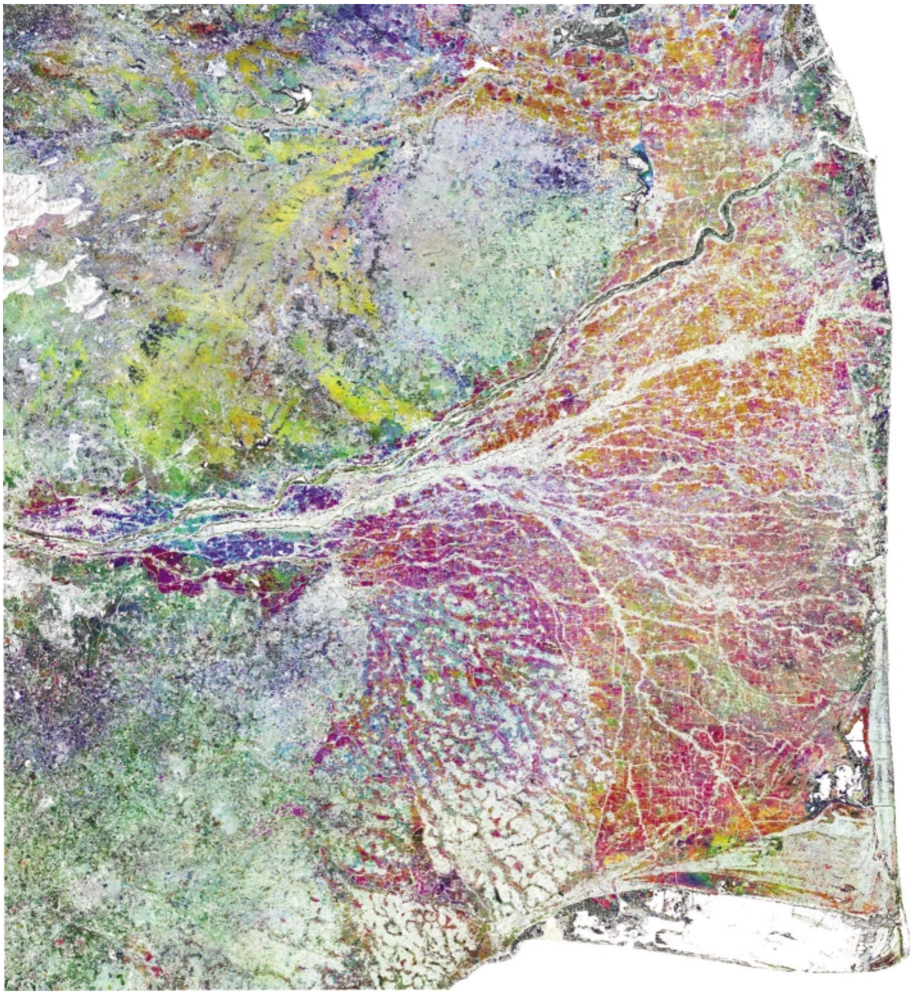


Figure C2. MAPscape-Rice processing of SAR raw data

and validating dedicated software to process Synthetic Aperture Radar (SAR) data supported with *in situ* information gathered using ICT and to integrate SAR information with other inputs for ORYZA crop growth model to simulate and map rice yield results. MAPscape-Rice processes SAR raw data into terrain-geocoded images (see Figure C2 for the process). Figure C3 shows an example for Tamil Nadu in the Republic of India. Similar maps were produced for the Mekong Delta rice area (Figure C4a), and for start of season (SoS) (Winter Spring) for the Mekong Delta (Figures C4b and C4c), and leaf area index products. Rice-YES integrates remote sensing information from MAPScape-Rice together with climate, soil, and agronomic management information to simulate rice yield using ORYZA crop growth model and together with MAPScape-Rice the yield simulation results are converted into a map form.

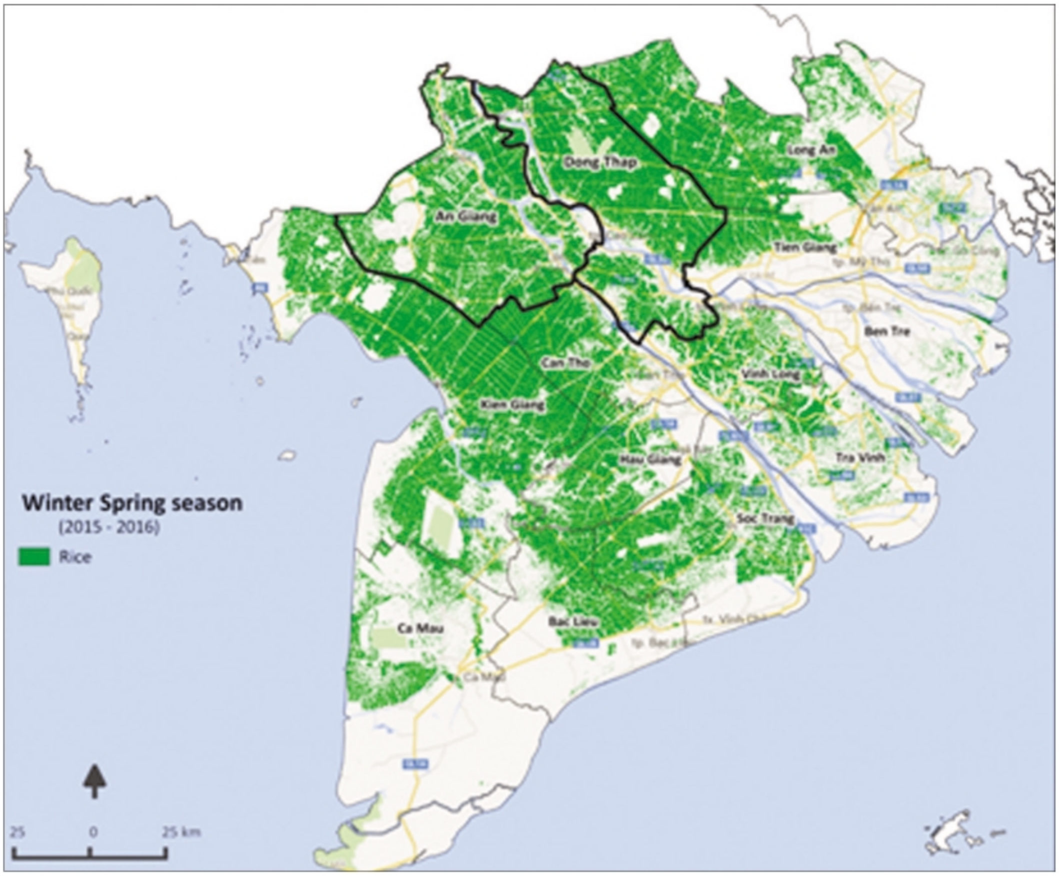
In the case of natural disasters such as resulting from flood and drought, a map of the impacted area, particularly the rice area, is generated by the system. The system provides more detailed information on the flood impacted rice area in contrast to the conventional information on the flood-affected area more generally.



Note: Light blue to magenta colours indicate cultivated rice fields whereas light to dark green represent forests. Information derived from these data contributes in acceleration of insurance pay out impacting more than 200 000 rice farmers who were not able to plant their rice during the Samba 2016 season because of insufficient water.

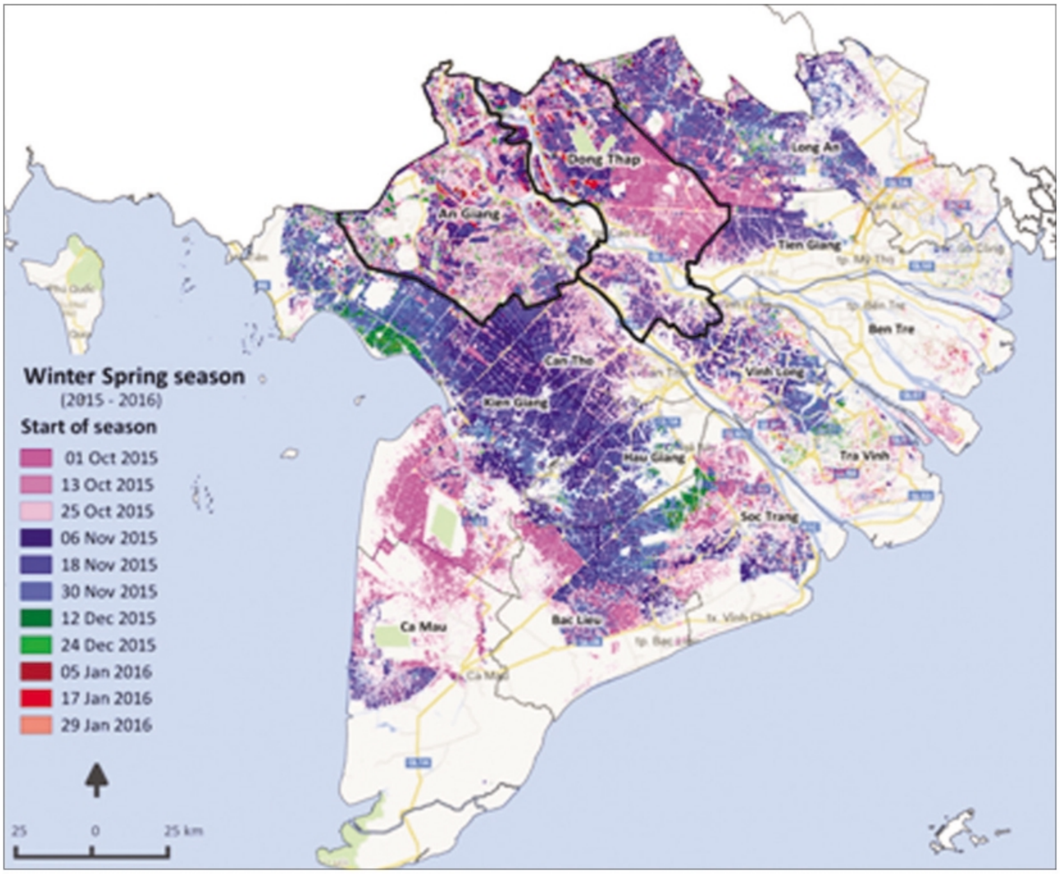
Credits: Tamil Nadu Agricultural University (TNAU), Remote Sensing-based Information and Insurance for Crops in Emerging Economies (RIICE), European Space Agency (ESA).

Figure C3. Processed SAR data over Tamil Nadu, India, in the Cauvery Delta region from Sentinel-1 in 2016



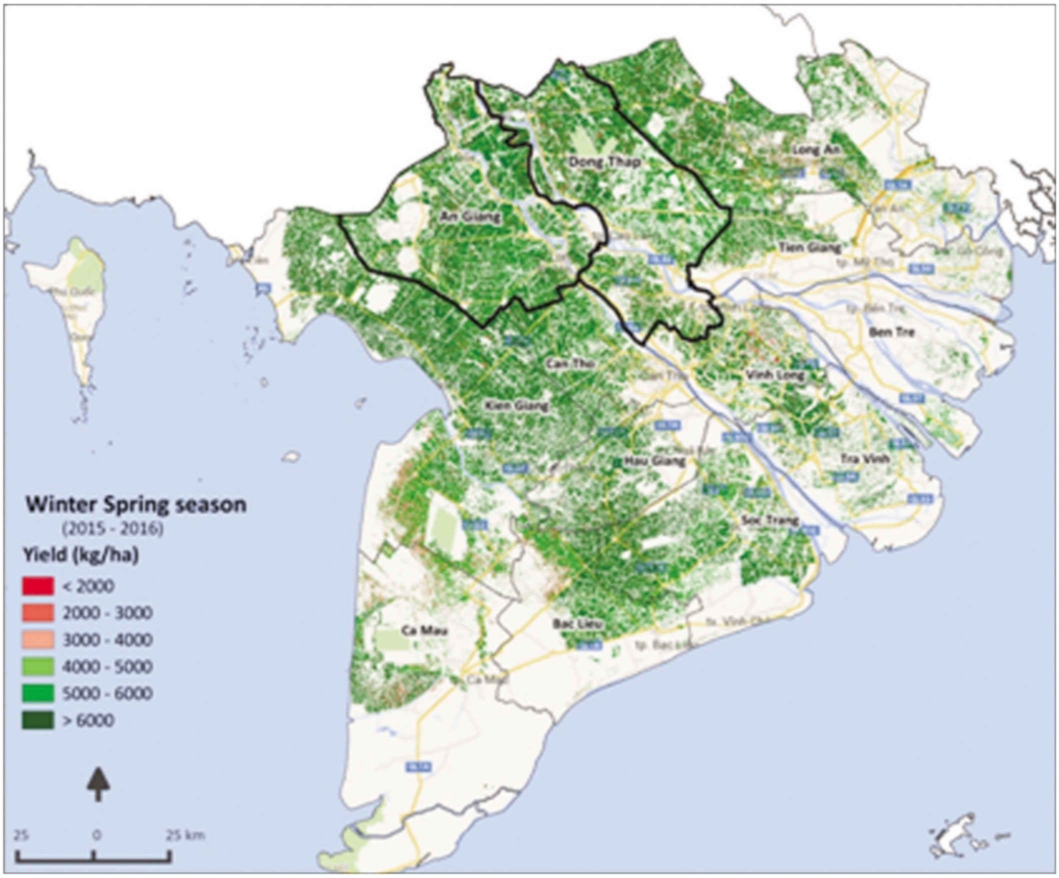
Credits: RIICE, European Space Agency-ESA.

Figure C4a. Rice area for Mekong Delta, Viet Nam for Winter Spring season 2015-2016 derived from SAR Sentinel-1 data and *in situ* information



Credits: RIICE, European Space Agency-ESA.

Figure C4b. Start of Season map for Mekong Delta, Viet Nam for Winter Spring season 2015-2016 derived from SAR Sentinel-1 data and *in situ* information



Credits: RIICE, European Space Agency-ESA.

Figure C4c. Yield map for Mekong Delta, Viet Nam for Winter Spring season 2015-2016 derived from SAR Sentinel-1 data and *in situ* information

Rice area and yield information were made available to the stakeholders in a timely manner and at accuracy and agreement level greater than 85 percent based on ground-truthing the rice area map assessment and comparison against official yield data and crop cut yield data. The practice also delivers a protocol for field and landscape level observation of rice crop health status, including assessment of the impact of pest and disease and lodging on rice production using an unmanned aerial vehicle (UAV) system.

Challenges

Rule-based algorithms for SAR data processing and flexibility in interface for remote-sensing and the ORYZA crop growth model were the key in addressing the challenges of site-specific variations of the location setting. Early in the project, it was realized that because of the varied rice ecosystem even within a country it was not possible to use a single set of parameters for earth observation processing in order to produce reliable rice monitoring products. Ground information is very critical in providing inputs to ensure quality and relevancy of the output of satellite-based rice area and seasonality maps, for example.

Context and problem addressed by ICTs

The SRM initiatives aim to provide more detailed, location-specific, timely, and accurate estimates of rice production. Such information is crucial for planning and decision making related to food security. This includes assessment of potential shortfall in production requiring decisions on whether to import rice, better targeting of productivity enhancing technologies, and rehabilitation and relief in the event of a calamity.

Often, data on rice production are not available at the required level of detail. For example, in the Republic of the Philippines, official production statistics are available at provincial level only. Although unofficial municipal statistics are available, their accuracy and reliability varies by location. With the use of high resolution SAR data, rice areas can be estimated at a finer level of detail. Municipal and even village level data can be estimated if a good digital administrative map is available. Problem areas, such as those with low yields can be located and thus targeted for technology dissemination. Moreover, estimates can be available two months in advance of official statistics.

In the event of a calamity, quickly obtaining estimates of the area damaged is a challenge because of mobility issues resulting from flood, road obstructions, and/or infrastructure damages. Also, there is a tendency to report higher damages to expedite the release of calamity funds. In such cases, an unbiased source of information is needed.

The effort started by relying on commercially obtained X-band SAR data from Cosmo SkyMed (CSK) and TeraSAR-X (TSX) after the failure of the European Space Agency (ESA) ENVISAT (C-band) mission in April 2012. The original plan was to rely on C-band SAR data from ASAR ENVISAT satellite. This resulted in downscaling the coverage, in order to keep project costs feasible, while focusing on methodology development to process the earth observation data. In the early phase of the project, activities were dedicated to developing correlations between rice growth parameters and SAR signatures, automatization of the earth observation processes, and development of and interface linking remote sensing data with the crop growth model ORYZA and preparing weather data and other inputs needed to run yield simulation. Throughout the project duration, the methodology for capturing *in situ* data for model calibration and validation were also refined with ICT implemented using Geo-ODK software in smartphones and *in situ* LAI collection using smart phone application. The practice aimed to address the challenges of site-specific variations in rice ecosystem caused by differences in agro-eco-climatic setting and crop cultivation practices and to manage accurate and timely delivery of the rice monitoring products.

Impact

RIICE Phase I (2012 to 2015) demonstrated in 13 sites in six countries in South Asia and Southeast Asia that the methodology presented can accurately map rice areas across different environments and crop management practices (Nelson *et al.*, 2014). Because of promising results in the pilot sites and the potential of the suite of technologies for operational rice monitoring, governments have come forward and entirely funded the development of their own rice monitoring systems. The Philippine Department of Agriculture (PHL-DA) has funded the PRISM project to develop an operational rice monitoring system for the whole country to guide decision-making and planning related to rice security. Under this project, a sustainability plan was developed to enable the smooth transition from research to operation with the handover of the entire operation of PRISM to the PHL-DA through the Philippine Rice Research Institute (PhilRice), a key project partner in PRISM. Currently, PRISM data are being evaluated and used by the PHL-DA Rice Programme and PHL-DA Regional Field Offices (RFOs) to complement existing data and other sources of information. Likewise, the state governments of Odisha and Andhra Pradesh in the Republic of India, have provided funds to IRRI to map and monitor rice areas in their respective states for use in crop insurance. More Indian states are expected to do the same in line with the Prime Minister's crop insurance scheme launched in February 2016. Several damage assessments have been conducted since 2012, one of which is the mapping of flood damage extent resulting from typhoon Haiyan (local name: Yolanda), a category 5 tropical cyclone that caused catastrophic destruction in the Visayas islands in the Republic of the Philippines in November 2013. Likewise, the timely provision of flood maps and statistics in Cuddalore district in Tamil Nadu, Republic of India in November 2015 helped identify the flood affected areas and facilitated relief and rehabilitation measures undertaken by the state government. The local government acknowledged that the flood assessment report was used to rapidly provide relief materials such as seeds and seedlings to 400 flood affected farmers in Cuddalore district (Gille, Pazhanivelan and Yadav, 2016).

Remote sensing-based assessment was also done to quantify the impact of the 2015 and 2016 El-Niño rice production in Mindanao island in the Republic of the Philippines, the Mekong River Delta in the Socialist Republic of Viet Nam, and in the Kingdom of Cambodia. In 2016, Tamil Nadu was hit by the worst drought in 140 years. The technology was used to identify affected villages, and 200 000 farmers from these villages benefited by getting insurance claims in record time (European Space Agency, 2017).

Constraints

During project implementation various challenges were encountered including communication problems, unfulfilled expectations, technical glitches and limitations. Challenges encountered by "next users" include difficulty in interpreting results and different expectations of results in terms of format and coverage. The challenges were addressed by improving communication channels and frequency, resolving technical issues and resorting to more efficient options for IT solutions, which include the use of Amazon Web Service (AWS) for processing raw SAR data. Feedback from the next users was used to improve the format and coverage of the outputs to meet their needs and expectations. Capacity building efforts continued in each country at various levels to develop in-country skill sets.

Lesson learned

- identify key stakeholders, plan how to engage them, and involve them early;
- find champions and keep them informed and engaged;
- clarify and manage expectations;
- foster regular discussions, open and effective communication, and joint-decision making with key project partners;
- build capacity to use products and sustain the system; and
- create opportunities for reflection, evaluation and joint-learning.

Sustainability and upscaling

The practice is sustainable given that the SAR satellite data from ESA Sentinel-1 mission are provided at no cost with an operational mission of seven years from the Sentinel-1 A and B constellation with possible extension beyond such duration with the Sentinel-1 C and D constellation. Moreover, technology know-how was transferred successfully to government agencies and academic institutions with a mandate to carry out the practice beyond the project duration.

This practice to some degree has been replicated but not in the same context in terms of goal and institutional environment. Although rule-based algorithms and flexible remote-sensing with respect to crop growth model interface ensure that the crop monitoring system can be adapted to the different rice ecosystems, the caveat is that it is necessary to have accurate ground intelligent information to set the system in place for specific geographical locations. At present RIICE technologies are being replicated in various Indian states (Odisha, Andhra Pradesh) and there are plans to expand in other Indian states as well as other countries such as the Republic of the Union of Myanmar.

References

European Space Agency. 2017. *Sentinel-1 speeds up crop insurance payouts.* [online]. [Cited 14 August 2017]. http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1/Sentinel-1_speeds_up_crop_insurance_payouts).

Gille, S., Parzhanivelan, S. & Yadav, M. 2016. RIICE remote sensing-based flood assessment helps Government of Tamil Nadu, India in directing flood relief measures. ASEAN Sustainable Agrifood Systems, 9 February. [online]. [Cited 14 August 2017]. https://www.asean-agrifood.org/riice-remote-sensing-based-flood-assessment-helps-government-of-tamil-nadu-india-in-quickly-directing-flood-relief-measures/).

Li, T., Angeles, O., Marcaida III, M., Manalo, E., Manalili, M. P., Radanielson, A., & Mohanty, S. 2017. From ORYZA2000 to ORYZA (v3): An improved simulation model for rice in drought and nitrogen-deficient environments. *Agric. For. Meteorol*., 237: 246–256.

Nelson, A., Setiyono, T., Rala, A.B., Quicho, E.D., Raviz, J.V., Abonete, P.J., Maunahan, A.A., Garcia, C.A., Bhatti, H.Z.M., & Villano, L.S., *et al.* 2014 Toward an operational SAR-based rice monitoring system in Asia: examples from 13 demonstration sites across Asia in the RIICE project. *Remote Sensing*, 6: 10773–10812.

Setiyono, T.D., Quicho, E.D., & Romuga, G.C. 2017. Rice Yield Estimation System (Rice-YES) User Manual. International Rice Research Institute. Los Baños, Philippines.

For more information

Nasreen Islam Khan
Senior Scientist, Theme and Cluster Leader, International Rice Research Institute
n.khan@irri.org

Tri Setiyono and Alice Laborte
Scientists, International Rice Research Institute (IRRI), Philippines
t.setiyono@irri.org; a.g.laborte@irri.org


Photo by Stephan Müller/Pexels.com

Actionable intelligence from drones to the agricultural industry

EXPERIENCES FROM SAP

Photo by Quangpraha from Pixabay

The application of drones to agriculture has developed in exciting ways over the last three years and SAP's innovations in this field, namely its Leonardo® IOT and HANA® technologies related to memory databases and analytics, are making important contributions.

This chapter will review the recent history of drones applied to agricultural problems, look at how farmers' and growers' demands from drones are changing, and finally, present two cases where SAP drone software is being used to solve real world agricultural problems in two diverse agricultural sectors: bush/tree based cash crops (e.g. bananas) and cattle ranches. The focus will be on the technology benefits that software processing of raw data output from drones bring to the agri-sector, i.e. using the outputs from the drones to provide meaningful insights into an agri-business.

Recent history of drones in agriculture

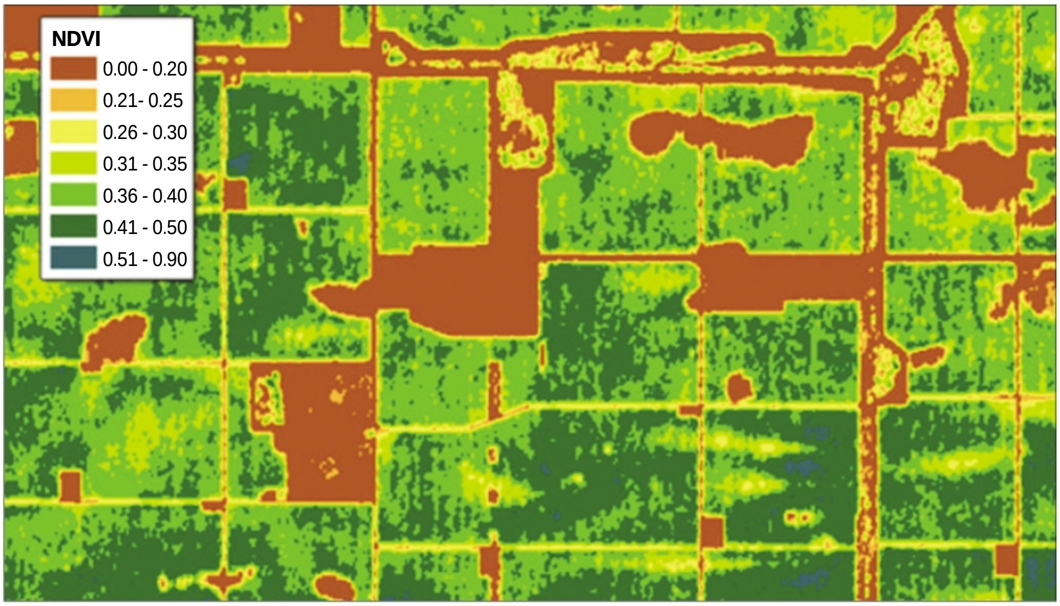
The well-documented potential for drones to revolutionize agriculture reached its zenith in 2015. Drone technology captured the imagination of investors, entrepreneurs and farming businesses alike as a means to replace certain tasks on the farm and play a role in "precision agriculture" – the modern farming technique aimed at making production more efficient through the precise application of inputs and machinery (Burwood-Taylor, 2017).

The promise of drones not only centred on crop scouting through imagery captured by the drone, but also on applying inputs such as pesticides. The start-ups that raised funding in 2015 were split broadly into two categories: the unmanned aerial vehicle (UAV) manufacturers and the drone software platforms mapping out flights and providing some analysis of the images received. Some did both. The focus in this chapter will be on the analysis of the images received.

Towards the end of 2015, there were signs that expectations for the technology in agriculture may have been inflated. One potential indicator of this could be the 64 percent drop in funding for drone start-ups and applications in 2016 compared to 2015. But, more importantly, the signs also showed in the agriculture community.

In the early days of using drones to capture aerial imagery, just having an aerial image of your farmland, added great value. The idea was that farmers could fly over their fields as often as they wanted to pinpoint issues, such as irrigation leaks, leaf colour variation, or pests like nematodes. Soon, however, this information was not enough and farmers complained they were getting less and less value out of the images. Although the images could help them plan their days better by highlighting where these issues were occurring, it was becoming apparent that by the time the imagery informed them about certain issues, it was often too late to remedy the situation.

Farmers soon wanted more from their images and the term “actionable intelligence” (Eisaian, 2017) has become popular among start-ups and investors relating to the technology (Burwood-Taylor, 2017). The first step in providing this actionable intelligence was producing crop health maps for farmers to pinpoint areas of potential yield loss. This was achieved by measuring the amount of biomass or live green vegetation in the crops using near-infrared (NIR) sensors (Roderick, Smith and Ludwick, 1996) that can detect vegetation levels based on the amount of light reflected off the leaves – the higher the biomass content, the more light that is reflected. These vegetation levels use the Normalized Difference Vegetation Index (NDVI), a simple graphical indicator for these measurements, to produce what are commonly called NDVI maps (Holme, Burnside and Mitchell, 1987). These maps show crop health through colours, which vary from dark green/blue for areas with most vegetation to red for the least healthy areas (see Figure D1).



Source: DroneDeploy (no date)

Figure D1. An example of an NDVI map depicting crop health

The challenges

Many early drone technologies for agriculture relied on uploading images to the cloud for processing or even returning to a computer to upload and then push through to an analytics programme to create the NDVI maps. With limited mobile phone coverage in many agricultural regions, and large distances to travel between fields and the office, farmers and agronomists have complained that this can become an arduous process. And, without the benefit of real-time, actionable insights in the field, many believe the technology is not worth their time and cost.

SAP's next wave of drone technologies for agriculture – SAP Leonardo

The commoditization of drones, which can now be purchased for as little as a few hundred dollars, has also made the actual vehicle for flying of less importance; now it's all about the sensor attached to the drone, the processing and analysis of that imagery, and the real-time, actionable insights that analysis can give to farmers. To answer this call, SAP launched SAP Leonardo (METOS, no date) in 2016. This is a digital innovation platform especially tailored to adding insights to data captured from any IoT platform – the very actionable insights that growers and farmers are craving (Figure D2).

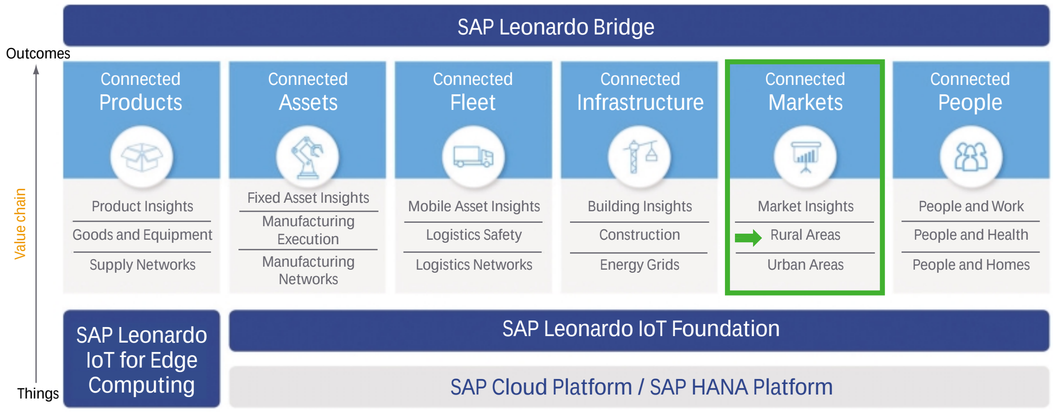


Figure D2. SAP Leonardo – a digital innovation platform

SAP Leonardo innovation portfolio for Internet of things (IoT) solutions integrates technologies and runs them seamlessly in the cloud. Its Design Thinking (SAP, no date, a) methodology recognizes the fact that each farmer's and grower's exact requirements are different from a standard software offering, though they may share many of the attributes of prior solutions. For example, data captured from a drone can be incorporated into a system in a standard way that should not have to be re-written every time an application is deployed, but how the data is analysed and displayed could well change from farmer to farmer. To this end, Design Thinking offers a standard methodology to quickly brainstorm and prototype solid solutions using standard Leonardo® software components.

Drone-based sensors are particularly suited to agricultural applications. Sensor technology and the IoT can be leveraged to collect precise agricultural machinery data, as well as weather and soil data. In fact, as of the last quarter of 2017, the agri-business sector is the pre-eminent sector for the civil use of drones. The use cases are many, including drones and robots being used to diagnose pests and crop diseases, monitor fertilization and irrigation status, and, increasingly, automate fertilization or crop protection tasks. In addition, farmers are getting connected to the global value chain through mobile technology even in the most remote rural areas.

SAP Connected Agriculture

The vision for SAP Connected Agriculture using the Leonardo drone-based IoT platform is to support new business models and processes in agri-business. This includes enabling insight creation and constant optimization of processes and practices by leveraging smart algorithms. A good example of this was cited previously in this chapter – using drone-based sensors and GIS overlay data to produce NDVI crop maps.

An important design attribute is that the IoT platform uses HANA Cloud. The amount of data that can be collected is staggering, vastly in excess of any cost-efficient traditional on-site storage. For example, a typical drone carrying five sensors complemented by 15 other IoT sensors in the field, with peak sensor data bandwidth of ~50 terabyte/month, sampling at ~1Hz and conducting 10 to 20 field operations per season for a 2 000 ha/farm can produce the equivalent of 50 000 GB worth of data.

Apart from using the cloud to consume and store the data easily, HANA Cloud also has fast analytic capabilities. Again, as cited in the recent history of drones section above, growers have moved on from simply viewing aerial pictures of their fields and paddocks to demanding actionable intelligence. The HANA analytics platform allows speedy analytics of the captured data, as we will see in the use case examples discussed later in the chapter.

Finally, a challenge for remote locations is the lack of connectivity to stream drone sensor data to the cloud for processing. This is not a new challenge and has been seen in other industries, especially mining. Numerous hardware and software technologies exist that solve this issue and some are listed below, but the message is that even remote off-grid farms and regions can benefit from actionable intelligence from drones, for example:

- local Wi-Fi receiving stations can be powered by batteries/charged from solar cells;
- smart intelligence, which varies the duty load of the drone receivers/Wi-Fi receiving stations based on battery charge, will be available (i.e. if batteries are charged then they can have a more frequent surveying schedule);
- on-farm pre-processing of data can reduce the amount of data to be uploaded to the cloud by a half to a third – this can be done simply by compressing files;
- a network of local Wi-Fi to get to a point where the data can be uploaded can easily be created; and
- on-drone storage for post flight data upload will be available.

In order to create decision level actionable intelligence**,** we need to consume not only data from drones, but from all information sources available. It is clear that data captured via drones alone will not give us the complete picture of the environment and must be used in conjunction with GIS data, weather data, in-field IoT data, farm machinery data, agriculture commodity price data, fertilizer commodity price data and other agro-economic sources to give us the best decision tool. This is what Connected Agriculture using the Leonardo IoT platform strives to do by enabling collaboration through standardization and open interfaces using Leonardo Foundation Technical Services.

The SAP Cloud Platform IoT services can be used to connect devices to the SAP Cloud Platform in order to use data from these devices in applications. The communication can be two-way, not only connecting to remote devices to manage the life-cycle from on-boarding until decommissioning, but also to receive device data and send commands to remote devices (e.g. turning on-farm and off-farm irrigation units based on analysed drone data).

Real world use cases

Two practical real world use cases of SAP's Leonardo Connected Agriculture suite connecting drones to provide innovative solutions to two very different agricultural problems provide important lessons.

Use Case 1: Cash crop surveying – a complete recorded history from seedling to maturity

Many cash crops can benefit from drone surveying to improve the yield outcome and profitability for the grower. Tree/bush-based cash crops such as banana, cotton, fruits, nuts and forestry are often overlooked in favour of higher turnover market garden crops.

The Leonardo Connected Agriculture suite has been deployed to prove concepts/prototypes for many of these industries, with the aim of providing a historical record of the lifecycle of a cash crop tree, from sapling to maturity. The advantages of this record keeping are that the growers have:

- a history of all agriculture actions applied to the cash crop tree/bush;
- absolute proof that the crop comes from areas of established plantation, the provenance being recorded on a blockchain record, down to the tree/bush level;
- a record of pest or blights affecting the trees;
- a record of inputs to the tree, e.g. fertilizer/manpower/insecticide;
- information on profit and loss at tree/bush level;
- a record of seeds harvested from the tree and links to new tree saplings produced (a hereditary hierarchy); and
- an analysis of yields and actions to improve crop quantity and quality.

Yields are an important concern to any cash crop owner. New land for planting is hard to come by, either because of the expense of buying farmland or restrictions on clearing forested areas or unsuitability of certain land areas for cropping. Therefore to meet the global demand for food as global population increases, improving yields is paramount.

It is important here to consider the scale of the task. For plantations to be commercially successful, growers often have to upscale their operation. Banana plantains of 2 000 acres are common and surveying such a large area efficiently needs some thought. In a Design Thinking workshop, a number of solutions were brainstormed. Although IoT sensors are cheap and plentiful, the sheer number required to tag every tree in a plantation and the wired or wireless infrastructure required to support the IoT sensors was deemed impractical.

Drone overfly of fields/forestry/plantations coupled with GIS data and advance processing was the chosen solution and has since been implemented in the project. What follows is a discussion on how the images are captured and processed, and the value added to the collected information using the power of Connected Agriculture and HANA® advanced analytics to produce actionable insights.

Capturing the plantation

Inexpensive commercial drones are used to overfly a bush/tree plantation. The plantations are often well laid with the trees in a regular grid pattern, typically in strips 100 m wide by 1 km long. This makes it easy for human-controlled or automatous UAVs to map large areas of plantation quickly. A series of flat two-dimensional images are taken at different angles, with the position of the images being recorded using GPS coordinates. If anything, this is the easy part of the whole process. What happens next is where the power of digital analytics really comes to the fore.

Raw image processing

The thousands of images taken by the drones are stored in HANA for fast persistence. Then an open source tool called OpenDroneMap (OpenDroneMap, no date), which can be used open source toolkit for processing aerial drone imagery, is used to stitch together the thousands of images into three-dimensional (3D) geographic data that can be used in combination with other geographic datasets (see Figures D3 and D4).

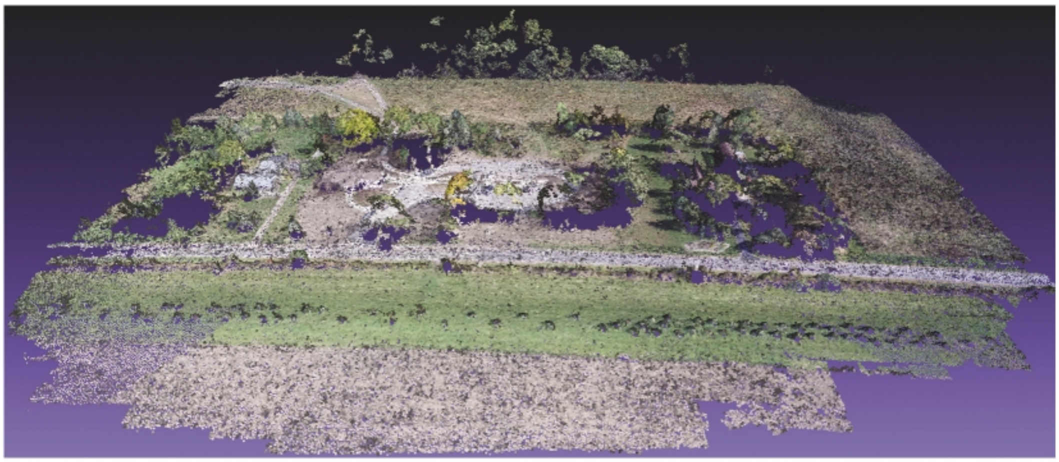


Figure D3. Three dimensional point cloud produced from thousands of images by ODM

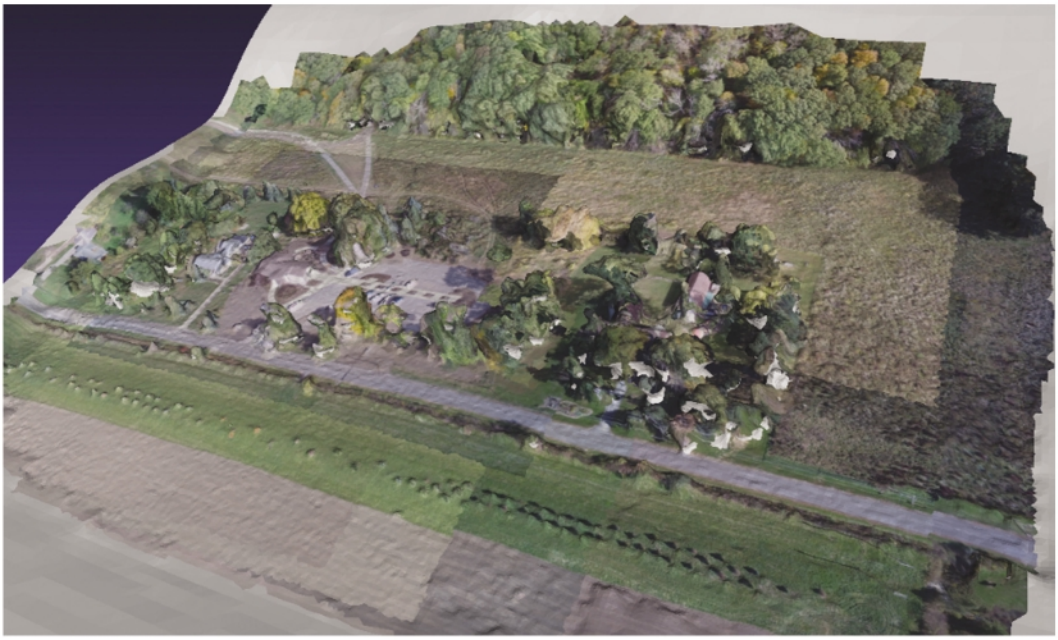


Figure D4. Three-dimensional model produced from image point cloud

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The next step is to use another image processing tool, Pix4D (Pix4D, no date). This is a solution to convert the 3D point cloud into 3D surface models based on advanced automatic aerial triangulation. This process is based purely on image content and unique optimization techniques.

The output of this process is a GeoTIFF file, which is a public domain metadata standard that allows geo-referencing information to be embedded within a TIFF file. The potential additional information includes map projection, coordinate systems, ellipsoids, data, and everything else necessary to establish the exact spatial reference for the file.

Creating GeoTiles and a pyramid of images

The final part of the process is to analyse the GeoTIFF, identify individual unique trees and add in historical/metadata to each individual tree. Planet.com/Esri are GIS services that provide GIS layer data that can be combined into the GeoTIFF. The SAP Objectstore adds in all the historical data recorded for each tree, e.g. yield, fertilizer records, harvest records. The SAP Geoservices layer effectively creates a pyramid of images from which the user can drill up and down through the stack, right down to an individual tree. The end product of this processing is a GeoTile that captures all information about an individual tree in an easy to serve and process object. A GeoTile is typical at a 100 m^2, but it is possible to drill down to an individual tree/bush.

Finally, **Connected Agriculture** (SAP, no date, b) is used as the front-end tool for the growers to interact with their digitized plantations (Figure D5) – Connected Agriculture can produce many attributes, even down to the tree level to record all and every action applied to that tree over time.

Figure D5. Connected Agriculture Interface

According to the SAP Proof of Concept, a plantation manager can use the Connected Agriculture interface to replay time and see how the tree/plant/bush has developed and matured over 30 years. The manager can also look at the inputs provided to that tree, again between any two points in time. HANA Analytic (SAP, no date, c) in Connected Agriculture can be used to understand the impact of actions. For example, did costly fertilizer prove beneficial in improving yields? How did the rainy season affect the ability to harvest? Are the weather conditions such that the farmer is at risk of pest infestations in certain localities?

The important point to remember here is that the technology that enables drones to survey is mature. Drones are becoming commodity items and very capable units can be purchased for a few hundred dollars. Sensors are inexpensive too.

What has been missing up to now is the ability to store and process the vast amounts of data produced by even a simple drone pass. Raw data from a drone is just that, raw. It is of little use until it is processed. In the SAP Proof of Concept, explained above, the images are stitched together, processed into point clouds, external data from GIS sources are added, and then database objects that form the basis of the analytics are created. Some of the most useful tools for actionable intelligence are scenario testing using the Leonardo Machine Learning (AI) engine (SAP, no date, d).

Farmers, growers and plantation managers can enter many “what if” scenarios and view the outcomes graphically in Connected Agriculture. SAP’s machine learning digitally models a farm and gives insights into potential outcomes based on varying inputs. For example, what happens if there is a drought? How is yield affected? Is it worth paying for crop protection – will the resulting extra-protected yield justify the costs?

Once the data is in the digital domain, a whole host of technologies can be applied to create actionable information. Through feedback, the Leonardo Machine Learning engine becomes tailored to an individual plantation over time and there has been remarkable accuracy when comparing predictions to actual outcomes.

Use Case 2: cattle farming

In this second use case, we look at IoT solutions for cattle farming. Although cattle farming has evolved since the 1800s when cowboys drove cattle along the open ranges of the American west, ranchers still lose sleep over the same questions: Where are my cattle? Are they healthy? How many calves were born last week? Do my animals have enough grass and water? Which predators are in the area? All of these factors can influence the rancher’s bottom line.

The economics of cattle farming increasingly favours big herds requiring ever-larger grazing areas managed by fewer caretakers – from ranches in the United States of America, to the People’s Republic of China, the Federative Republic of Brazil, the Republic of India, the Republic of Argentine or the Russian Federation and the numbers are truly staggering. One major agribusiness in the Russian Federation, for example, aspires to grow its herd to a million cattle grazing across 10 000 square kilometres. Monitoring territory of this size is a huge task, so farmers are increasingly looking to technology for answers, and they are finding inventive solutions based on the IoT – in particular the IoT solution supported by the SAP HANA Cloud Platform.

Digitalize to feed the world sustainably

In all industries, agri-businesses are becoming increasingly digitalized, a development which is viewed by many as key to feeding the world sustainably. Digitalization of their processes enables agri-businesses to increase productivity and manage food supply chains sustainably and transparently “from farm to fork.” Early adopters of IoT solutions in crop farming have already shown that sensor data across farms can be collected and analysed on a cloud platform.

The production process on cattle farms is similar worldwide. Mother herds graze in open green fields, bearing calves. Bulls reaching 220 kg are moved to separate grazing fields to mature. At about 400 kg, ranchers move the cattle to more densely populated feedlots where they remain until slaughtered at about 600 kg. The cycle is continuous and the challenge is to maximize output while ensuring quality and minimizing operating costs.

Spotting the calves, protecting the herd

The prototype developed by the SAP envisages a cattle collar with sensors for location (GPS), motion (accelerometer) and temperature. Batteries need to keep the collar transmitting for the life of the cow, up to three years. The current cost per collar is about USD 25, however that cost will drop significantly.

Sensor data can be combined to tell whether a bull or cow is sick, trapped, lost or deceased. According to one study (Helwatkar, Riordan and Walsh, 2014), accelerometers can distinguish up to nine different cattle diseases. Temperature can indicate a dead bull, which if left undetected might spread disease to others. An animal that is alive (temperature) but static (GPS) could be injured or trapped. The pictures delivered by a drone can also deliver useful information about a herd, such as pasture grass quality or the number of newly born calves. Where it is clear that predators have struck, ranchers can take preventative measures.

As with any operation in remote territory, there are technical challenges. Perhaps the most innovative part of the SAP solution is the way sensor data is transmitted from the herd to drones. RFID can transmit only ten metres, bluetooth is susceptible to weather conditions, and mobile communications networks seldom support underpopulated rural areas, so all three were not viable. Therefore drones and collars were outfitted with low-power wide area network (LoRa) transmitters and receivers. LoRa is a relatively new communications method intended for wireless battery-operated devices that supports sending data long distances at very low data-rates.

Data analysis supports "herd management by exception"

The interesting part begins once a drone completes its mission autonomously and returns to the farm with herd data. All sensor and picture data are uploaded to HANA Cloud Platform (SAP, no date, e) for evaluation. Cattle farmers can immediately analyse and evaluate the data to gain near-real-time status over their herds, develop action plans and even make predictions that support upstream and downstream processes of the business. With the information, cattle farmers can more easily adopt a "management by exception" working model, which helps them optimize the way resources are allocated.

Conclusion

Agriculture is the leading business for the application of drones. Given the huge number of hectares of land that are given over to agricultural activities and the remoteness (i.e. lack of wired or Wi-Fi infrastructure), this is perhaps not surprising. Drones are inexpensive and reliable. What has been missing up to now is the ability to add actionable insights into the data captured by drones. The challenges to doing this successfully have been shown to be:

1) processing the vast amounts of data captured (5 000 PCs worth in one month for 20 sensors at 1 Hz for a typical farm);

2) integrating multiple data sources on different protocols (e.g. GIS data, multiple sensor vendors, pre-processing of image data);
3) analysing the resultant datasets in a timely manner to produce actionable insights; and
4) presenting the actionable insights in a way that can be understood easily.

SAP has brought three of its technologies together to enable the information capture by drones to be effective. These technologies are:

(1) the HANA cloud database technology with limitless speedy data capture, retrieval and analytics;
(2) the Leonardo IoT suite to connect and exchange information over any protocol; and
(3) the Connected Agriculture suite to provide an intuitive and graphical front end to farmers and growers.

The lessons of the use cases can be extended to any agriculture challenge. Although tree/bush plantations and cattle herding were the examples given here, any agricultural management and decision support problem can be solved with this robust, mature and fit for purpose technology.

References

Burwood-Taylor, L. (2017). The next generation of drone technologies for agriculture. *Agfunder News,* 16 March [online]. [Cited 22 July 2017]. https://agfundernews.com/the-next-generation-of-drone-technologies-for-agriculture.html

DroneDeploy. no date. Plant health [online]. [Cited 12 August 2017]. https://support.dronedeploy.com/v1.0/docs/plant-health

Eisaian, A. (2017). Tansformational power of digital agriculture–why now? [online]. [Cited 17 September 2017]. https://www.intelinair.com/transformational-power-of-digital-agriculture-why-now/

Helwatkar A., Riordan, D. & Walsh, J. (2014). Sensor technology for animal health monitoring. Proceedings of the 8th International Conference on Sensing Technology, Sep. 2–4, 2014, Liverpool, UK. [online]. [Cited 13 July 2017]. https://www.researchgate.net/publication/265552275_Sensor_Technology_For_Animal_Health_Monitoring

Holme, A.McR., Burnside, D.G. & Mitchell, A.A. (1987). The development of a system for monitoring trend in range condition in the arid shrublands of Western Australia. *Australian Rangeland Journal 9*: 14–20.

METOS. no date. Integration with SAP Leonardo brings precision agriculture to a new level [online]. [Cited 13 August 2017]. http://metos.at/home/integration-with-sap-leonardo-brings-precision-agriculture-to-a-new-level/

OpenDroneMap. no date. OpenDroneMap: what is it? [online]. [Cited 14 July 2017]. http://opendronemap.org

Pix4D. no date. “Measure from images” [online]. [Cited 26 July 2017]. https://pix4d.com

Roderick, M., Smith, R. C. G., & Ludwick, G. (1996). Calibrating long term AVHRR derived NDVI imagery. *Remote Sensing of Environment* 58: 1–12.

SAP. no date, a. Design Thinking with SAP [online]. [Cited 28 July 2017]. https://designthinkingwithsap.com/en/

SAP. no date, b. Solution explorer. Connected agriculture [online]. [Cited 24 August 2017]. https://solutionexplorer.sap.com/solexp/ui/vlm/is_cp_agriculture/vlm/is_cp_agriculture-ind-is_cp_agriculture/is_cp_agriculture-bpr-479,is_cp_agriculture-e2e-1461,is_cp_agriculture-ist-4537

SAP. no date, c. Gain new insights from advanced analytical processing in SAP HANA [online]. [Cited 17 August 2017]. https://www.sap.com/australia/products/hana/features/advanced-analytics.html

SAP. no date, d. SAP Leonardo machine learning [online]. [Cited 12 August 2017]. https://www.sap.com/australia/trends/machine-learning.html

SAP. no date, e. What is SAP cloud platform [online]. [Cited 18 August 2017]. https://cloudplatform.sap.com/index.html

For more information

James Veale
Vice President Agri Solutions SAP APJ
james.veale@sap.com

Case study

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Drones-based sensor platforms

EXPERIENCES FROM TATA CONSULTANCY SERVICES (TCS)

Overview

Unmanned aerial vehicles (UAVs) or unmanned aerial systems (UAS), better known as drones, in a technological context are unmanned aircrafts that can be remotely controlled or fly autonomously. They work in conjunction with GPS and others sensors mounted on them. The total addressable value of drone-powered solutions in all applicable industries is significant – more than USD 127 billion, according to a recent PwC analysis. Drones have been mostly associated with military and warfare in the past but keeping pace with technological advancements, they have found application in a plethora of disciplines. With the world population projected to reach 9 billion by 2050 and agricultural consumption expected to increase by 70 percent over the same period, agri-producers need to embrace emerging technological advancements such as UAVs. Drones in agriculture are simply a low-cost aerial camera platform, equipped with an autopilot using GPS and sensors for collecting relevant data. They can be compared to a regular point-and-shoot camera for visible images, but whereas a regular camera can provide some information about plant growth, coverage and other things, a multispectral sensor expands the utility of the technique and allows farmers to see things that cannot be seen in the visible spectrum, such as moisture content in the soil, plant health, stress levels and fruits. These could help overcome the various limitations that hinder agricultural production. PwC estimates the potential market for drone-powered solutions in agriculture at USD 32.4 billion. UAVs application in agriculture opens the gateway to access real time information on the farm. It can be used at different stages throughout the cropping cycle:

- **Soil and field analysis** – After getting precise 3D maps for soil, planting can be planned and nutrient status can be analysed for further operations.
- **Planting** – UAS shoot seeds with nutrients in the soil with an average uptake of 75 percent, thus bringing down costs for planting.
- **Crop spraying** – Drones can scan the ground and spray the correct amount of liquid, modulating distance from the ground and spraying in real time for even coverage.
- **Crop monitoring** – Time-series animations can show the precise development of a crop and reveal production inefficiencies, enabling better crop management.
- **Irrigation** – Drones with hyperspectral, multispectral, or thermal sensors can identify which parts of a field are dry or need improvements.
- **Health assessment** – By scanning a crop using both visible and near-infrared light, drone-carried devices can identify which plants reflect different amounts of green light and NIR light. This information can produce multispectral images that track changes in plants and indicate their health.

Context and challenges

The Republic of India is a multiproduct agricultural nation with highly diverse topography, climate and soil. The country's small-sized, family farms practice a unique kind of mixed agri-horti-livestock farming, which is a cost-effective model ideal for other developing nations with small farms. Indian farmers multitask, and shift with ease from crop cultivation to animal husbandry, thereby remaining engaged throughout the year. By and large, this versatility has transformed the Indian agricultural sector and in 2016-2017 it contributed 17.32 percent to the country's Gross Value Added (Statistics Times, 2017). Despite the transformation, Indian agriculture is still limited by a number of factors including the unpredictable weather, scattered and small landholdings, non-scientific way of farming, poor technological adoption. It points to a dire need for technological intervention in the system. To keep pace with world agriculture, farming needs to be become more technologically driven. It has to be more reliant on real time information thus enabling the farmers to make more informed decisions. There are several challenges pertaining to the implementation of UAVs in the agricultural context:

- **Quality software –** Right from planning the flight path till processing the final image, software plays a crucial role in the applicability of this technology.
- **Legal aspects** – Different nations have their own regulatory regimes pertaining to the use of UAVs in agriculture.
- **Acceptability on the farmer front –** Technological unawareness may be a hurdle in its penetration.
- **Flight time and flight range** – Most drones have short flight ranges thus limiting the acreage that they can cover. The ones with the longer flight ranges are relatively more expensive.
- **Initial cost of purchase –** Drones with features that are suitable for use in agriculture are quite expensive.
- **Interference with the airspace** – Drones share the same airspace with manually manned aircraft.
- **Connectivity** – Mostly farmlands may not have good connectivity, thus either the farmer has to invest in connectivity or buy a drone capable of capturing data locally for later processing.
- **Weather dependency** – Drones' operations are heavily dependent on climatic conditions, thus limiting their usage.

Benefits for stakeholders, partners and end users

This is a promising technology offering immense value across the entire crop value chain, including the stakeholders – from farmers to consumers.

The Farmers – They are the main and direct beneficiaries of this technological intervention. They get access to real time information pertaining to their farms and thus are enabled to make informed decisions. They can plan their entire cropping cycle, optimize farm operations and reap maximum benefits. The initial cost of implementation may be high but when estimated in conjunction with the output benefits, it is surely a feasible technology that should be adopted. Moreover, crop damage can be highly reduced by utilizing data from crop health indices. This leads to an increase in farmers' net return from their farms.

The input partners – This mainly includes the input-output companies that form a crucial link in the agricultural value chain. Optimizing farm operations and a data driven approach may help companies in advance planning of their stocks.

Credit and insurance institutions – Credit and insurance companies also benefit and business processes are simplified for them. Insurance companies can effectively disburse the monetary compensation based on real time data from the field with much more reliability. Similarly, the credit worthiness of a farmer can be better justified on a digitized farm.

Farm mechanization industry – Mechanized operations on the farm can be made more precise and thus resource use can be optimized.

The middlemen in the supply chain – Utilizing the crop yield indicators and scheduled harvesting can help aggregators plan accordingly and save on the costs of the operations.

Food processing industry – Similarly, the procurement by the food processing institutions can be well planned and aggregated utilizing farm data that gives details of the crop, acreage, yield and harvest time. Thus companies may enter into pre-purchase agreements with farmers and the output marketing becomes a lot simpler for them.

The technology

TCS has fully autonomous multirotor drones designed and built in-house. It uses innovative electronics and structural health monitoring with multiple safeguards. It has a long range with high endurance and a high payload capacity. There are configurable multipayloads; multispectral, visual and thermal cameras. It is offered in customizable range, payload and radio frequencies. It is suitable for multiple applications such as wildlife conservation, forestry, agriculture, infrastructure inspection.

Specifications of the UAV

1. Type: Quad-rotor (4-rotor helicopter) (Figure E1)
2. Power: Battery powered electric motors
3. Size (length x width x height): 2 feet x 2 feet x 1.5 feet)
4. Weight: 4.5 kg
5. Payload: Camera for monitoring crop health
6. Safety features Geo-fence (height set to 60 m), automatic return to home in case of radio failure or low battery.

Figure E1. TCS Quad-rotor drone

© TCS

Cases of implementation

Case 1: Drones for precision agriculture

TCS employs the use of drones for agriculture by acquiring multispectral data for crop health monitoring, soil mapping and irrigation. It then utilizes cloud-based data analytics for early detection of water and nutrient stress and pest infestation. This ultimately ensures delivery of actionable insights to the farmers on their handheld devices.

Crop health analysis – TCS drones capture multispectral and visual imagery of the farm (Figure E2). An accurate crop health analysis is then done using various crop health indices. It helps in the early detection of nutrient deficiencies and other problems. Advanced algorithms have been developed for species identification, population estimation and localization.

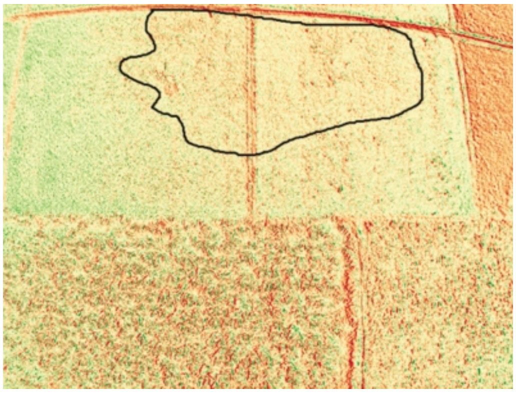
Figure E2. Tea plantation – health mapping using multispectral imaging by drones

© TCS

Early detection of crop health problems – Similar imaging and advanced algorithms can help in classifying areas in the field for different crop health indices (see Figures E3, E4 and E5).

© TCS

Figure E3. Productivity variations in rice paddy



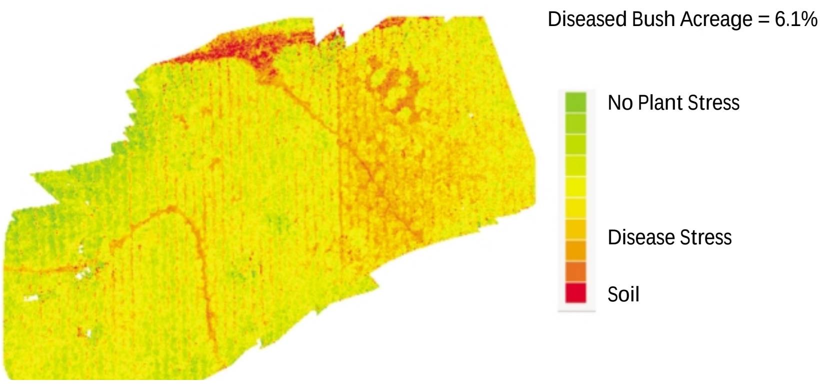
© TCS

Figure E4. Poor tillering in rice paddy

© TCS

Figure E5. Productivity variations in rice paddy

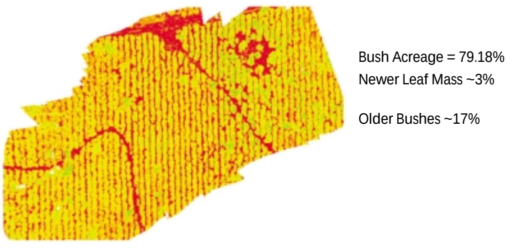
Disease and pest incidence – This was studied successfully in tea plantations based on the Plant Stress Index level. Multispectral images were taken and disease incidence was high in places that showed higher level of plant stress (Figure E6).



© TCS

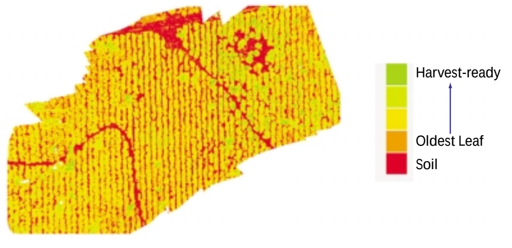
Figure E6. Disease and pest incidence in tea plantations

Estimation of acreage – Drone technology can be successfully employed to estimate the acreage of the planted crop and crop stage of the plantation (see Figures E7 and E8). Based on this information, harvest decisions can be planned accordingly.



© TCS

Figure E7. Crop acreage in tea plantation



© TCS

Figure E8. Crop acreage maturity level in tea plantation

Case 2: Drones in forest plantations

TCS has successfully employed the drone application in forest plantations for estimating a number of characteristics. High-resolution elevation maps are created and key forest figures are estimated:

- Tree count and height (Figures E9 and E10)
- Area and volume estimation

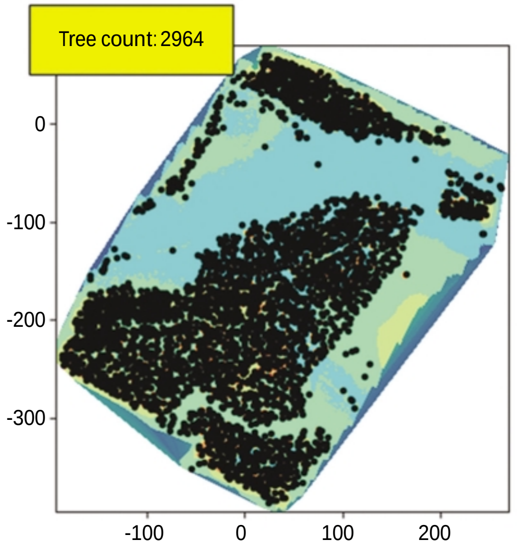


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Figure E9. Tree count

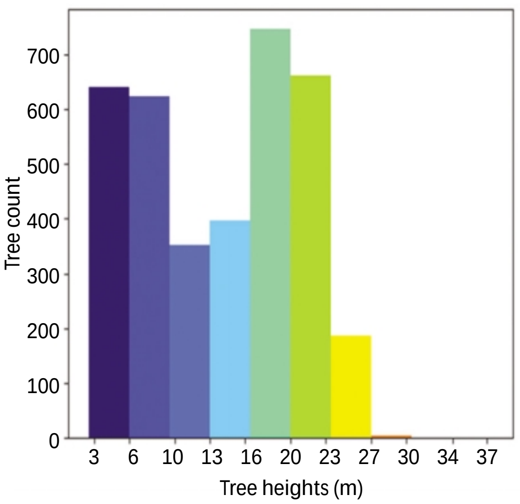

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Figure E10. Tree height histogram

Estimation of canopy diameter – This estimation is performed through a process of continuous iterations of "fitting an ellipse" across the visible canopy of the target tree. A threshold of 1 200 iterations was employed for the purpose. The major axis of the ellipse for each tree was considered to be the diameter of the associated crown (Figures E11 and E12).

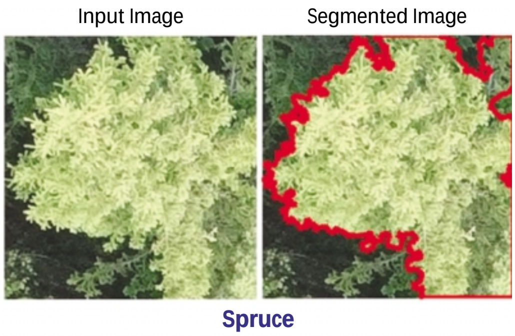

Figure E11. Canopy diameter estimation in spruce

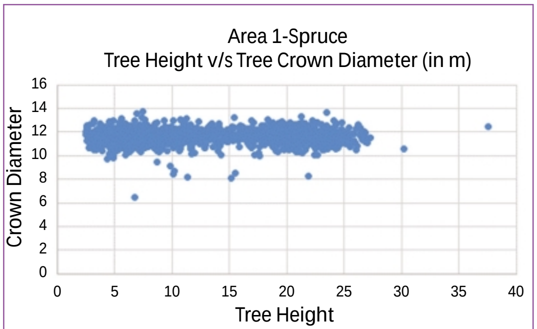

Figure E12. Tree height, crown diameter result

Species recognition and proximity assessment – Deep learning algorithms are used for tree species identification (Figure E13) and common infrastructure detection (Figure E14). It is also employed for assessing proximity.

Figure E13. Species identification (coconut)

Figure E14. Water area detection

Case 3: Wildlife conservation at Kaziranga National Park

The operation for conservation is taken care of by a set of actions done for monitoring the animals at the park (Figure E15 to Figure E18). These include:

1. Training

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Figure E15. Training at Kaziranga National Park with use of UAV

2. Routine surveillance

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Figure E16. Routine surveillance using a drone

3. Anti-poaching operations

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Figure E17. Anti-poaching operation using a drone

4. Wildlife monitoring

© TCS

Figure E18. Wildlife monitoring at the park using a drone

Looking ahead: potential of drone technology to alleviate agricultural problems

The utility and benefits of drone application in agriculture are well documented. The real time nature of information and its precision will be the key driver for agricultural development. With rapid adoption and continuous innovations, the technology will become more and more accessible to the common farmer. However, adequate training and awareness is a must for its deeper penetration into the rural masses. The future of UAVs in precision agriculture comes down to farmers being ready and willing to try out the technology for themselves. Regulation will continue to evolve and new advances will keep changing our conception of what drones can do. Getting involved now helps farmers acquire an understanding of the tremendous potential of drones and also allows them to determine their own way forward.

References

Statistics Times. 2017. Sector-wise contribution of GDP of India [online]. [Cited 12 August 2017]. http://statisticstimes.com/economy/sectorwise-gdp-contribution-of-india.php

For more information

Srinivasu P.
Global Head of TCS Digital Farming Initiative
srinivasu.p@tcs.com

Gopi Kandaswamy
Senior Scientist at TCS Research and Innovation
gopi.kandaswamy@tcs.com

Use of unmanned helicopters for agriculture

EXPERIENCES FROM YAMAHA MOTOR CO., LTD.

In 1983, a commission was received from the Japan Agricultural Aviation Association (an external organization of the Ministry of Agriculture, Forestry and Fisheries) to develop a remote control aircraft capable of performing aerial (airborne) spraying of agrichemicals, or what became known as a remote control aerial spraying system (RCASS). Initially Yamaha worked only on an engine, but recognizing the importance of the end product operating as a complete package led to Yamaha taking charge of developing the RCASS entirely and the research and development (R&D) work on this began. The prototype was dubbed the "Aero Robot RCASS".

Another request from the same organization was for the craft to use counter-rotating rotors (a helicopter format in which two rotors on the same axle rotate in opposite directions). Yamaha focused its R&D efforts on achieving this and used a liquid-cooled 2-stroke single cylinder 292 cc engine for the prototype. A helicopter with counter-rotating rotors has no need for a tail rotor, making it more compact. But that also means that controlling pitch (rotating about the y-axis), roll (rotating about the x-axis) and yaw (rotating about the z-axis) becomes uniaxial, making the required mechanisms more complex to engineer. A Flight Test Stand (FTS) (Figure F1) was developed and the team worked on making the prototype ready for practical use, but factors such as the characteristics of servomotors at the time made flying the helicopter manually very challenging.

© Yamaha Motors

Figure F1. A flight training device was developed as work on implementing the RCASS progressed

So, the team decided instead to use gyro sensors – a cutting-edge technology at the time – and fully automated flight tests were carried out to verify design validity (Figure F2). However, the aircraft still weighed over 100 kg, so practical use would still have to wait.

Figure F2. Final prototype of the RCASS (1987)

Developing and improving the base model

The R-50 (Figure F3) was developed alongside the RCASS. It used a main rotor/tail rotor format and was powered by a liquid-cooled 2-stroke, 2-cylinder, 98 cc engine. The R-50 was the world’s first unmanned helicopter for crop dusting capable of carrying a 20 kg payload. But this initial model did not feature any electronic governance as the main priority was to establish a base platform for unmanned helicopters.

Figure F3. The R/-50 prototype model (1987)

R&D began on incorporating electronic altitude control for the R-50. This would allow the operator to concentrate more fully on spraying the fields below. An ultrasonic sensor was tested, but the rice paddies would absorb the waves and negate effectiveness. A laser sensor was tested after that and it worked well, so it was adopted for a system Yamaha developed to control the helicopter's altitude, the Yamaha Operator Support System (YOSS). YOSS was eventually implemented on the R-50, but it was overly sensitive to uneven terrain in actual use and this version was later removed from production.

But further evolution came in 1995. Fibre-optic gyros developed for car navigation systems were utilized to develop the Yamaha Attitude Control System (YACS), which featured an operator-controlled model-tracing device to respond more faithfully to steering commands. It was added to the R-50 and went on sale the same year.

With early versions of the R-50, the operator had to use the control stick and fly the helicopter the entire time from takeoff until landing. But with the introduction of YACS, information gleaned from the three fibre-optic gyros and accelerometer could be processed and used to make automatic control of all axes of flight possible. The R-50 was capable of mounting spray equipment and a tank for agrichemicals and performing aerial (airborne) spraying of rice paddies, reducing the time and labour of spraying a hectare of rice paddy from an average of 160 minutes to just about ten minutes (Figure F4).

© Yamaha Motors

Figure F4. The R-50 uses the downwash from the main rotor to assist in spreading agrichemicals on the target area

Expanding fields of activity

The RMAX was introduced in 1997 and featured a newly designed engine, and was followed in 2000 by an RMAX equipped for automatic flight (built-to-order model; used to investigate the eruption of Mount Usu). The RMAX Type II G and Type II (Figure F5) were introduced in 2003 with functions that made them easier to fly, and the RMAX G1 that featured fully automatic flight geared towards industrial use was released in 2006. The 4-stroke FAZER model went on sale in 2013, followed by the FAZER R in 2016.

© Yamaha Motors

Figure F5. The RMAX Type II G comes with a high-precision GPS (2003)

Usage in Japanese agricultural market

Today, approximately 2 800 industrial-use unmanned helicopters such as the “RMAX” and “FAZER” are registered for operation in Japan’s agriculture industry, where they spray a total area of over 1.05 million hectares per year, or about 42 percent of the country’s rice paddy area under cultivation. By simple calculation, this means that one in every three bowls of rice served in Japanese homes has been grown with the agrichemical pest control spread by an unmanned helicopter.

Over the 25 years since the birth of the industrial-use unmanned helicopter, Yamaha Motor Co., Ltd. has continued to develop know-how and technical advancements to make these helicopters as efficient and safe to use as possible. One of these areas of know-how is the training of the operators that fly them. Only people who have been through a demanding training curriculum can be licensed to fly and maintain these helicopters, and presently there are about 11 000 licensed operators active in Japan. Yamaha has also worked with numerous research institutes to expand the range of uses for the helicopters. They are now being used for the direct sowing of rice paddies and pest control in vegetables, wheat/barley and soy bean agriculture. More recently, they have been used overseas for similar purposes in countries such as the Republic of Korea and Australia.

For more information

Masatoshi (Mike) Endo
Group Manager Overseas Marketing Group Marketing Division
UMS Business Development Section
Yamaha Motor Co., Ltd.
endoumas@yamaha-motor.co.jp


MAVIC PRO

Case study

G

Space technology use in crop insurance

EXPERIENCES FROM INDIA

Photos by Pixabay from Pexels

Crop yield estimation at the lowest specified administrative level is the most important indicator in the crop insurance scheme *Pradhan Mantri Fasal Bima Yojna* (PMFBY) of the Government of India for deciding insurance claims. For crop yield estimation, the well-established methodology of Crop Cutting Experiments (CCE) has been in use so far. However, for accurate assessment at lower administrative level (village or village *panchayat* level), the requirement of a huge number of CCE with utmost precision has been a cause of concern as it may not be practically feasible. In the current methodology of yield estimation, the allocation and selection of plots for conducting CCE is based on statistical information and carried out using random numbers. The current year crop situation (area sown and crop condition) is not taken into consideration. This makes CCE plot selection not properly representative of the actual crop situation. Additionally, carrying out such a large number of CCE, as desired under the new crop insurance programme may not be practically feasible. Hence, the approach documented here could be a possible option.

There is a need to optimize the CCE locations using satellite remote sensing data, which not only provide the crop area map, but also indicate the crop conditions. In order to evaluate and validate this a large number of pilot studies were carried out in different parts of the country. During the monsoon or rainy season of 2015, pilot studies were carried out in Kurukshetra, Shimoga, Yavatmal and Seoni districts of Haryana, Karnataka, Madhya Pradesh and Maharashtra states, respectively. During the winter season of 2015-2016 two districts were selected in each state: in Haryana, Hissar district and Karnal district; in Karnataka, Raichur district and Gulbarga district; in Maharashtra, Ahmednagar district and Solapur district; and in Madhya Pradesh, Vidisha district and Hoshangabad district. During the winter season of 2016-2017 the study was replicated in one block of each state selected during 2015-2016, for validation of the approach. The blocks identified for the study were Ratiya of Fatehabad (Haryana), Shorapur of Yadgir (Karnataka), Babai of Hoshangabad (Madhya Pradesh) and Karmala of Solapur district (Maharashtra).

Multidate satellite remote sensing data is used for mapping the particular crop area, with the support of ground truthing. For rice crop, multidate microwave SAR (Synthetic Aperture Radar) satellite data are used, whereas for wheat and other crops multidate optical (visible and near infrared) remote sensing data are used. The examples of SAR satellite are RISAT-1 of the Republic of India, RADARSAT-2 of Canada and Sentinel-1 of the European Space Agency (ESA). Optical data is taken from Resourcesat-2 of Republic of India, Landsat-8 of the United States of America and Sentinel-2 of ESA.

Again, multidate moderate resolution satellite (e.g. MODIS or AWiFS) data are used for computation of remote sensing based vegetation indices, such as Normalized Difference Vegetation Index and Land Surface Wetness Index. These two indices indicate crop vigour and crop water status, respectively. Based on these two indices, the whole district is classified into 4 groups/strata – Very Good (A), Good (B), Medium (C) and Poor (D). The crop map generated from high-resolution satellite data is overlaid on this crop condition map to generate a condition map with respect to a specific crop. CCE points are selected randomly within each stratum, proportionate to the number of pixels under each stratum (Figure G1).

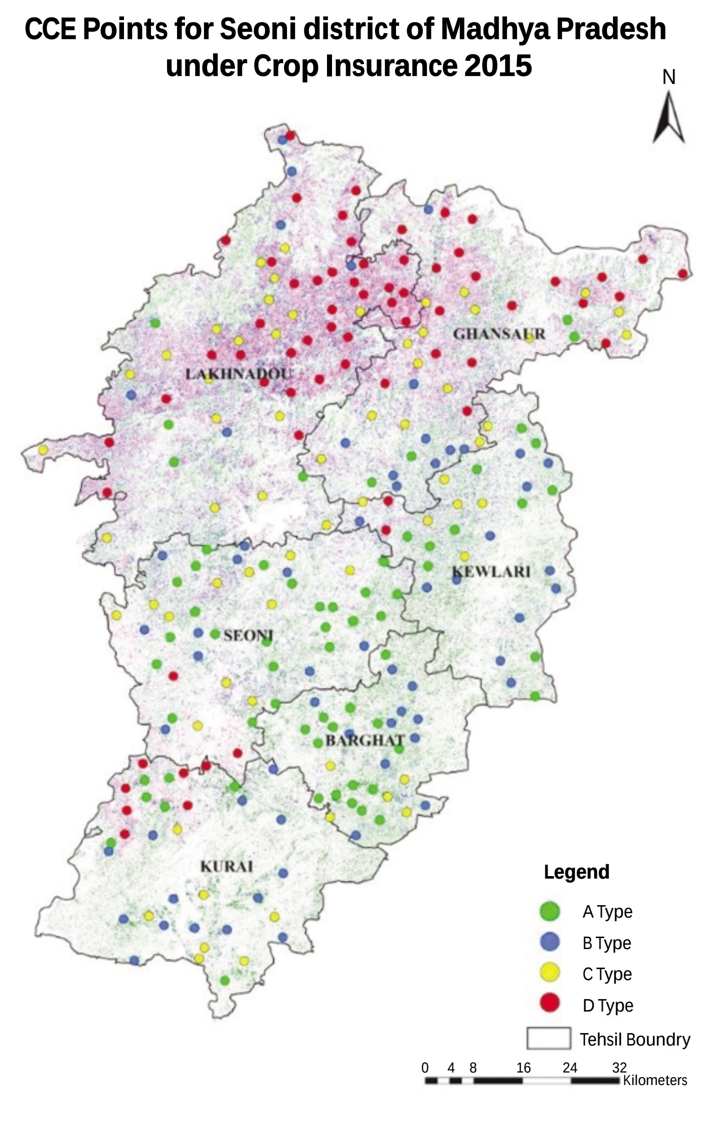


Figure G1. Crop Cutting Experiment (CCE) sites planned based on remote sensing data

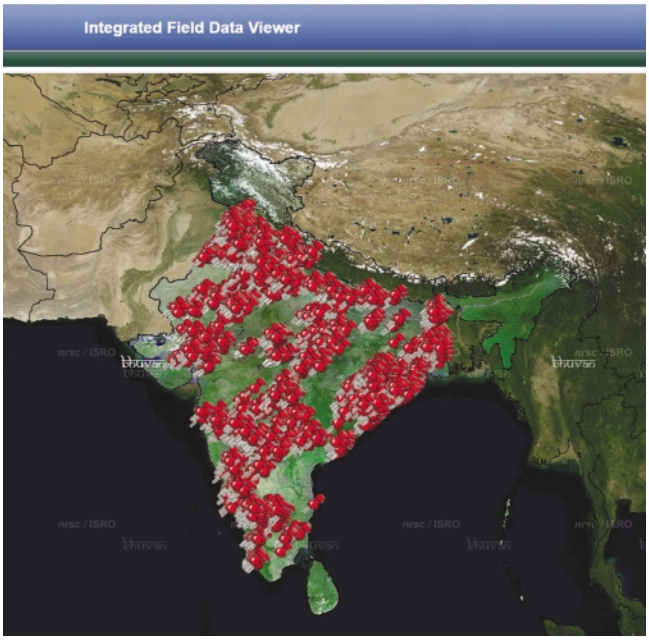
The National Remote Sensing Centre, ISRO, has developed an Android app for collecting CCE data, along with geographic location and field photographs (Figure G2).

Figure G2. Android app being used for CCE data collection using smartphones, developed by NRSC, ISRO

All the CCE data collected using smartphones are uploaded real time to ISRO's Bhuvan geoportal (Figure G3).

Analysis of this data has shown that CCE planning using remote sensing based indices is statistically efficient and hence it would optimize the number of CCE. Based on the success of these studies, the Karnataka state government used this approach for operational CCE planning during the monsoon season of 2016 and the Odisha state government used this approach for the rice crop during the rainy season of 2017.

Also, the guidelines of the country's crop insurance programme, PMFBY, advocate the use of satellite data for optimization of CCE and the use of smartphones for CCE data collection has been made mandatory (Government of India, no date).



© MoAF, India

Figure G3. Crop Cutting Experiments data uploaded to ISRO's Bhuvan platform

The user of this technology will be the state agriculture departments and the insurance companies. However, the farmers will benefit indirectly from this technology, as it ensures more accurate and timely CCE data collection, which is essential for deciding crop insurance claims.

Various factors have contributed to the success of this work:

- the urgent need for improving/rationalizing the CCE;
- the long experience of use of satellite data for crop assessment in the Republic of India;
- the availability of a large variety of high resolution satellite data;
- smartphones have become easily accessible in the country;
- the availability of the Bhuvan Portal for geographical data storage;
- the regular exercise of capacity building of state agricultural department officials by MNCFC for smartphones-based data collection;
- the showcasing of this technology in various forums – seminars, workshops, training etc.

Nevertheless, there are still many limitations in the use of this approach.

- As of now, the operational crop area estimation using satellite data is being carried out for eight crops (rice, wheat, cotton, sugarcane, potato, rapeseed, mustard, jute and sorghum). Hence, the remote sensing-based CCE planning approach is limited to these eight crops, as a crop map is essential for CCE planning.

- Even among the eight crops mentioned above, for some crops (other than cereals) the relationship between remote sensing-based index and crop yield is comparatively poor. In these cases, remote sensing-based CCE planning may not be statistically viable.
- Remote sensing-based CCE plans can only be generated after a crop has reached the maximum vegetative stage. Hence, it provides very limited lead time for its field implementation.
- For the majority of monsoon season crops, getting cloud free optical data is difficult, because of persistent cloud cover during the rainy season. This limits the implementation of remote sensing-based CCE planning.
- Even though there has been a tremendous increase in smartphone use in the country, many field officials do not have access to smartphones. For them smartphone-based data collection is difficult.

Various lessons learned during the pilot studies and the implementation phase are given below:

- there was an overwhelming response by the implementing officials to learn the new technology;
- even with a comparatively lower number of experiments, yield values were statistically very close to the values derived from a large number of experiments conducted in a conventional manner;
- much new information about the crops (such as major variety, major agronomic practices, sowing and harvesting dates, harvest index, stresses) could be obtained from the data collected through smartphones;
- there is a need to use higher resolution satellite data to improve the crop classification accuracy; and
- there is a need to combine the remote sensing-based indexes with other yield controlling parameters, such as soil and weather, to improve the statistical efficiency of CCE planning.

Given the regular improvement in the quality of satellite data being available, and the tremendous growth in various other related technologies (e.g. UAV based imaging, big data analytics, cloud computing, crowd sourcing, sensor networks, Internet of things, artificial intelligence), this approach will also improve further.

The pilot studies have been carried out for different crops (rice, wheat, cotton and sorghum) in different agro-climatic regions of the country. The methodology has also been operationally implemented in Karnataka and Odisha states. Hence there is scope for replicating the approach and upscaling it to national scale, subject to the constraints mentioned above.

References

Government of India. no date. Crop Insurance [online]. [Cited 22 August 2017]. http://agri-insurance.gov.in/Pmfby.aspx

For more information

Shibendu S. Ray, Director
Sunil K. Dubey, Assistant Director
Mahalanobis National Crop Forecast Centre
Department of Agriculture, Cooperation & Farmers Welfare
Ministry of Agriculture & Farmers Welfare, Government of India
ncfc@gov.in

Case study

H

Photo by Sasint from Pixabay

Institutionalizing drone mapping applications for disaster risk management in agriculture

EXPERIENCES FROM MYANMAR

Introduction

The Republic of the Union of Myanmar is an ethnically diverse country with about 52 million people belonging to 135 officially recognized ethnic groups in 14 states and regions and Nay Pyi Taw as its capital. Over 70 percent of the population live in rural areas with farming, livestock, fisheries, aquaculture and other natural resource sectors accounting for over 60 percent of employment in the country, about 36 percent of gross domestic product, and about 30 percent of exports by value.

Agriculture is the backbone of the Republic of the Union of Myanmar's economy, but it is also one the countries at highest risk of natural disasters in Southeast Asia and is affected by four major natural hazards: earthquakes, floods, cyclones, and droughts. The Global Climate Risk Index ranks the country as Number 2 out of 178 countries in terms of vulnerability to climate change. Long-term studies have also shown that the country is vulnerable to increased risks from climate change, and climate change is increasing the impact of other shorter cycle natural hazards. Coastal regions, particularly Rakhine State and Ayeyarwady Delta Region, are at high risk for cyclones, storm surges and tsunamis. Much of the country, especially in the Central Dry Zone, is exposed to flooding and landslides during the rainy season, in addition to drought and fire during the dry season.

Consequently, agriculture was the most effected sector by disasters, accounting for half of all losses with rural livelihoods significantly impacted. The challenges call for more comprehensive approaches based on an integrated analysis of hazards, risks linked with land use, livelihoods planning and natural resource management.

Since March 2016, FAO Myanmar has been stepping up its efforts to strengthen government agricultural sector agencies in the areas of disaster risk reduction (DRR) and resilience, including the use of modern technologies to address existing data gaps and allow more timely and effective preparedness and response actions.

A new way of working

The World Humanitarian Summit has underscored the need to shift from reactively managing crises to proactively reducing risks and that planning, financing and decision-making should be underpinned by data and common risk analysis. The World Summit also affirmed that disaster response cannot be isolated from broader development and climate change adaptation efforts. As such, new ways of working were seen as critical to building community resilience and reducing risk and vulnerability related to natural hazards and climate change. The Sendai Framework for Disaster Risk Reduction has also recognized the need to increase the utilization of modern geospatial technologies and help promote better understanding of risks.

In September 2016, FAO began collaborating with the Department of Technology Promotion and Coordination, Ministry of Education through its Myanmar Aerospace Engineering University (MAEU) to explore the use of unmanned aerial vehicles or drones which, after a series of carefully structured activities, led to the institutionalization of the technology within the Ministry of Agriculture, Livestock and Irrigation (MOALI). The following section presents the key activities undertaken by FAO, MOALI and MAEU that resulted in the establishment of the MOALI Drone Mapping Team, which is now equipped with drones and technical skills that are highly specific to the country's context. FAO is recognized as the first UN agency to utilize drones for disaster risk management (DRM) in agriculture in the country with preliminary mapping approaches and methodologies inspired by the pioneering work of FAO and the Department of Agriculture in the Republic of the Philippines.

Exploring the application of drone mapping technology in Myanmar – the 2016 floods

Following the monsoon floods in Magway region in October 2016, FAO first explored the application of drones to DRM in agriculture in order to enhance understanding of hazard impacts and strengthen beneficiary identification by collecting timely and scientifically reliable information in flood-affected areas. The first set of drone mapping missions were carried out to kick off FAO's project activities of emergency response and resilience building supported by the Central Emergency Response Fund (CERF).

In order to determine a comprehensive set of aerial mapping approaches and protocols for agriculture, FAO and MAEU conducted a series of field-based trainings and test flights. FAO provided hands-on training to MAEU on rapid aerial assessment methodologies, DRR concepts and technical guidance on data processing.

With the use of unmanned aerial vehicles in areas determined by FAO and the Department of Agriculture (DoA) and MOALI, rapid mapping missions were carried out to inform village assessments and profiling, as well as beneficiary identification. Data gathered from drone mission outputs such as high-resolution maps of flood affected areas (Orthophotographs, Digital Terrain Models and Digital Surface Models) helped FAO and government experts strengthen beneficiary identification/selection approaches and effective disaster impact assessment in flood-affected areas and further support the multihazard risks analysis.

A total of about 3 600 hectares were successfully mapped with a ground resolution of up to 5 cm, which enabled both FAO and government agriculture experts to analyse and validate cropping patterns, land use, village profiles as well as disaster risks.

Mapping sites were identified based on:

1. standing crop and damage reports from the Department of Agriculture;
2. consultation with MOALI officials;
3. consultation with township and village officials; and
4. safety/logistics/ease of access.

This pilot activity has resulted in several positive impacts and the realization that the technology is highly useful and could be effectively institutionalized if the proper government entry points are tapped. Flood-affected areas are better understood and validation of affected areas can be carried out together with the community. Agriculture lands are also validated soon after the hazard occurrence to identify whether or not the land is already planted. Identification of beneficiaries is more reliable and effective and the highly reliable nature of the drone-derived data also helps address beneficiary prioritization issues at the field level. Since orthophotographs allow precise area measurements, agriculture emergency response teams are better able to estimate the required agriculture inputs such as seeds and fertilizers and even assist in effective planning for the next agriculture season. Irrigation systems and other water sources can also be analysed and the processed data are useful for future risk assessment and emergency planning.

From lowland to uplands: drone mapping technology in highly remote upland agricultural communities

In July 2015, torrential rains and cyclone Komen triggered severe and widespread floods and landslides in remote western Chin State, one of the poorest areas in the country. Chin State's capital city, Hakha, was the worst-affected region with heavy rainfall and landslides that displaced thousands and wiped out half of the city's farmland.

Following the success of the Magway region drone mapping activities in 2016 and the presence of a Japan-funded agriculture DRR and resilience project in Chin State, FAO again partnered with MAEU in March 2017 in close coordination with the Department of Agriculture and carried out mapping activities in selected landslide and erosion prone areas in Chin State. This was determined as a crucial step in terms of further understanding the applicability of the technology in remote and topographically complex landslide-prone and erosion-prone regions. Data derived from the drone missions in Chin State have allowed FAO and government experts access to high-resolution, high-accuracy and high-temporality (timely) landslide and erosion risk information that was not previously readily accessible (both in terms of cost and quality). The maps produced also allowed state, township and village agriculture and DRR officials to examine aerial images of selected communities in Chin State in stunning detail, thereby promoting an entirely different level of appreciation of agriculture land use features and components, as well as a clearer understanding of hazards and risks present in a community.

The mapping exercises allowed FAO and government experts to strongly demonstrate the applicability and technical validity of drone mapping technology in terms of generating useful information related to upland agriculture risks such as landslides and erosion, as well as the technology's potential in revolutionizing how agricultural communities understand their risks, and reduce hazard or disaster impacts.

Institutionalizing drone mapping technology and capacities for agriculture

Lessons learned from previous emergency response and resilience building activities by FAO have shown the importance of building capacities to apply technologies including mapping systems for all aspects of DRR (such as vulnerability and risk assessment, identification of beneficiaries, implementation and monitoring of risk reduction measures). FAO has continued to partner with MAEU to build capacities within MOALI related to the use of drone technology.

On 29 March 2017, with approval from the Minister's Office, MOALI, the MOALI Drone Team, a subset of the bigger MOALI DRR Task Force, was established by the government with FAO's technical assistance. The drone mapping team consists of 30 interdisciplinary experts from the different departments and universities across MOALI (including the Department of Agriculture, Department of Livestock, Department of Extension, Department of Agriculture Research, Department of Irrigation and Water Management, Department of Land Records and Statistics, the Agricultural Mechanization Department, Department of Cooperatives, Department of Agricultural Planning, the Yezin Agricultural University and the University of Veterinary Sciences).

The drone mapping team is in charge of utilizing this modern geospatial technology to enhance disaster preparedness and response activities of MOALI, and help address time-critical data gaps. The responsibilities of the Drone Mapping Team, as approved by the Minister's Office, MOALI, include:

- participate in training events related to drone operations, maintenance and data analysis for enhanced DRR in agriculture;
- carry-out regular flight missions;
- conduct damage assessment flight missions as needed; and
- carry-out regular maintenance on drones and other flight equipment.

Building on the examples and lessons learned from previous aerial mapping work by FAO and MAEU in Magway region and Chin State, FAO together with MOALI and MAEU then organized a training course on drone mapping operations and scientific applications for DRR in agriculture in support of the established Drone Mapping Team from 22 to 26 May 2017 (Figure H1). The week-long training course focused on operations and applications of drone mapping technology to DRR in agriculture, and to a broader extent its use in supporting mainstream agricultural production. The team was divided into two groups, Flight Operations and Data Processing, in order to maximize the expertise of the different members and operational efficiency. The Flight Operations team consisted of controllers/pilots and ground control station operators whereas the Data Processing team was in charge of pre-data collection and post-data collection procedures. Membership in a specific team was determined on the basis of technical expertise and practical skills (e.g. hand to eye coordination for drone pilots).

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Figure H1. Participants of the training course on drone applications in agriculture

In addition to training the Drone Mapping Team on DRR (and CCA linkages) and aerial mapping operations and data analysis, FAO in collaboration with MAEU also supported the development and provision of aerial mapping systems/tools including the construction of a drone fleet (2 hexacopters and 2 fixed-wing UAVs) whose design and instrumentation were informed by FAO-MAEU-MOALI recent experience in mapping both lowland riparian and highly remote upland agricultural communities (Figure H2). The drones are modular and will allow cost-effective selective repairs and upgrades across all drone components as MOALI capacities or mapping technology (or both), improve. In addition to drones, data processing equipment and software were also provided.

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Figure H2. An example of a fixed-wing drone

A total of four Flight Operations-Data Processing teams were created to allow simultaneous drone missions in line with the size of the current drone fleet. Each team was led by a senior MOALI technical officer.

On 29 August 2017, MOALI and the Ministry of Education (MoE) officially launched the MOALI Disaster Risk Reduction Task Force and Drone Mapping Team. The launching ceremony, held at the Department of Agricultural Research, was opened by H.E. Dr Aung Thu, Union Minister, MOALI, and H.E. U Ohn Win, Union Minister, Ministry of Natural Resources and Environmental Conservation (MoNREC).

Examples of ongoing drone mapping applications by the MOALI DRR Task Force and Drone Mapping Team

Agricultural research and production

Drone and payload: Custom designed MOALI-MAEU-FAO hexacopters fitted with NDVI Red + NIR cameras (Figure H3).

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Figure H3. Hexacopter fitted with cameras

Use of Normalized Difference Vegetation Index (NDVI) to support crop health monitoring, crop research and production (Figures H4a, H4b, H4c and H4d).

Promoting resilient livelihoods in agro-archaeological communities

There is ongoing exploration of how data from drones can improve production and build resilience against disaster risks/climate change impacts while enhancing archaeological conservation planning, especially in areas where spatial patterns influence cultural and religious practices (Figure H5).

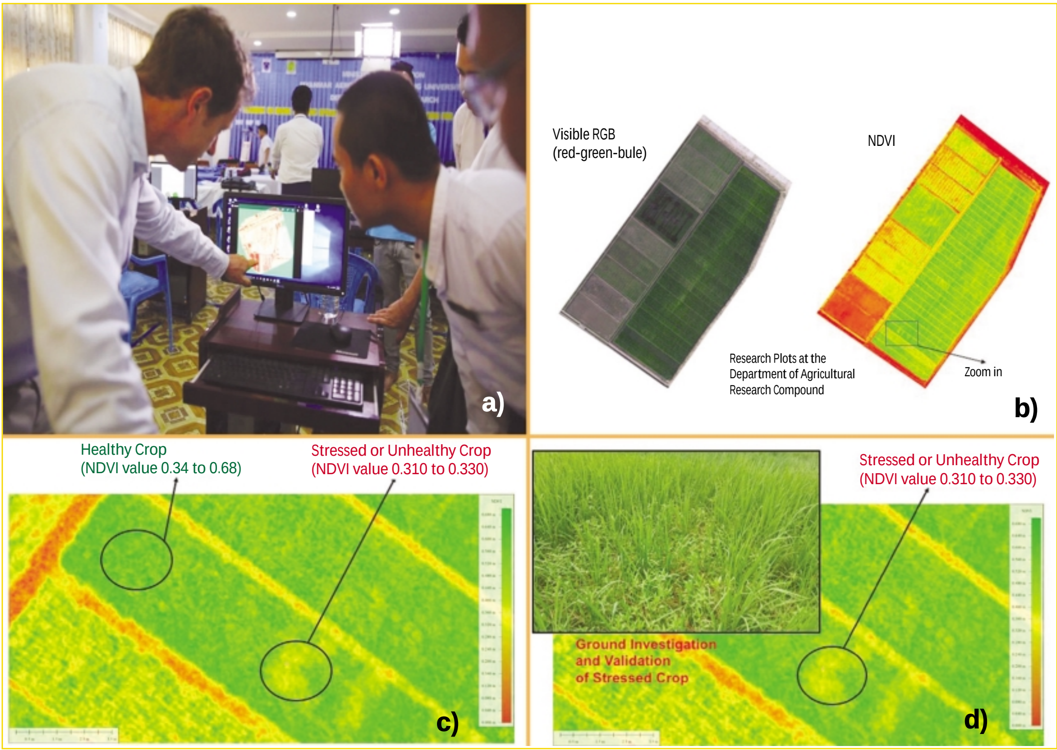

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Figure H4. a) Use of NDVI; b) Research plots; c) Healthy and unhealthy crops and d) Ground investigation of unhealthy crops

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Figure H5. Agro-archaeological communities in Began

Examples of drone mapping applications for disaster preparedness in agriculture

In an effort to enhance the reliability of cost-effective GIS-derived risk information (especially for topographically-complex areas), a drone-based Real Time Kinematic (RTK) Global Positioning System (GPS) was pilot-tested in Chin State. RTK GPS, consisting of a rover and base station (as seen in Figures H6 and H7), enabled centimetre-level precision as compared to metre-level precision of normal GPS (e.g. 1 metre normal GPS precision as used by MAEU and FAO during the CERF-supported September/October 2016 Magway region post-floods mapping). The RTK GPS-enabled drone mapping in Chin State resulted in up to 8 centimetres geo-precision. Combined with a map (image) resolution of up to 4 centimetres, the drone mapping exercise established a strong basis for the realistic application of the technology, even in one of the most remote regions of the country.

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Figure H6. The rover is attached to the drone

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Figure H7. The base station

Drone mapping technology revolutionizes community-based risk assessments and planning. The maps allow community officials to examine aerial images with very high detail, enables increased appreciation of agriculture and environmental features, and better understanding of hazards and risks (Figures H8 and H9).

Applications for emergency response

FAO in partnership with MAEU conducted the mapping of flooded areas in Magway region to aid the design of flood interventions for agriculture. Drone mapping missions (see Figure H10) through a CERF-funded project that was carried out during the 2016 Magway floods covered the agro-ecologically representative sampling areas in two of the most flood-affected townships in Magway region. A total of about 3 600 hectares were successfully mapped (Figures H11 and H12) with a ground resolution of up to 5 centimetres, which enabled both FAO and government agriculture experts to analyse and validate cropping patterns, land use, village profiles as well as disaster risks.

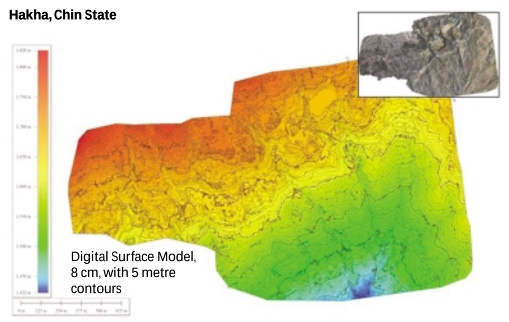

Figure H8. Digital map showing land contours

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Figure H9. Community-based risk assessment

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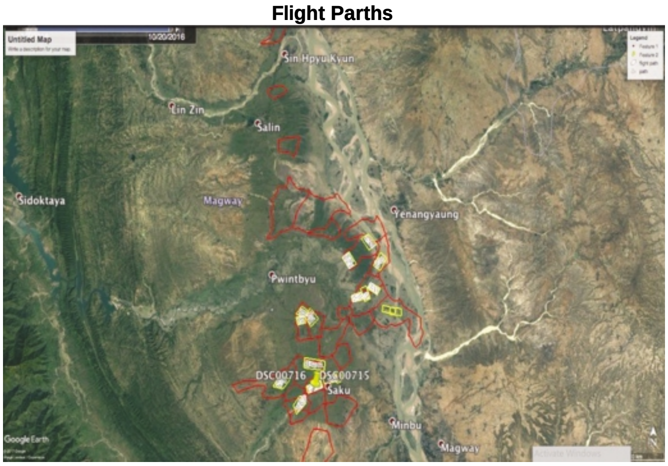

Figure H10. Drone mapping missions

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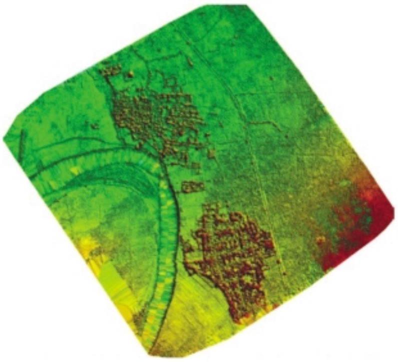

As a complement to ortho-photographs, high-resolution Digital Surface Models (DSM) enable robust analysis of elevation and other geophysical features of project villages that are important both for multi-hazard risk assessments and design of project interventions.

Figure H11. High-resolution (HR) DSMs

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High-resolution ortho-photographs allow accurate area measurements and detailed visual analysis of various features of project villages by FAO and government experts (Pwintbyu Township, Magway). Size: 2.6207 km² / 262.07 ha / 647.924 acres.

Figure H12. HR orthophotographs

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Mapping sites were identified based on:

1. Crop damage reports from the Department of Agriculture (red polygons)
2. Consultation with MOALI officials
3. Consultation with township and village officials
4. Safety/logistics/ease of access.

Promoting drone mapping technology within and across sectors

Recognizing the significant challenges related to accessing reliable and objective information before and immediately after a disaster or major hazard beyond the agriculture sector, FAO in July 2017 facilitated a collaborative mapping activity upon the request of the Relief and Resettlement Department (RRD), Ministry of Social Welfare, Relief and Resettlement.

A pilot collaborative drone team comprised of representatives from the Relief and Resettlement Department (MSWRR), MOALI, Myanmar Aerospace Engineering University (MAEU), and FAO conducted a pilot drone mapping mission in Pokokku and Minbu/Saku Township from 26 to 28, July 2017. Coordinating with local authorities and Air Traffic Control (ATC), the collaborative mapping team produced aerial maps and conducted real time video monitoring for emergency response and resettlement of flooded areas in Pakuoku and Myintbu townships in Magway region.

To sustain and further enhance the use of the technology, FAO is currently initiating a project that will support MOALI, MSWRR, DMH and MoE in designing and pilot-testing a methodology that will allow timely and cost-effective community profiling and assessment focused on disaster and food security risks. This includes the development of rapid ground-based data gathering methods whose speed and robustness/reliability will be supported (and justified) through modern aerial assessment methods while enhancing inter-ministry coordination/cooperation.

For more information

Roberto Sandoval
Disaster Risk Reduction/Climate Change Specialist
FAO Myanmar
roberto.sandoval@fao.org

Photo by Mali Maeder from Pexels

Drones for community monitoring of forests

EXPERIENCES FROM PANAMA

Community forest monitoring project

REDD+ is a voluntary climate change mitigation approach to reducing emissions from deforestation and forest degradation, conserving forest carbon stocks and sustainably managing forests in developing countries. The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) is a multilateral body that partners with developing countries to support them in establishing the technical capacities needed to implement REDD+. It was established in 2008 and is based on the convening power and technical expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP). The UN-REDD Programme supports nationally-led REDD+ processes and promotes the informed and meaningful participation of all stakeholders – including indigenous peoples and other forest-dependent communities – in the national and international implementation of REDD+. The UN-REDD Programme has been an essential partner through the comparative advantages of each agency, in the case of the community forest monitoring project[1] referred to in this chapter FAO supported the forest monitoring in indigenous territories.

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[1] Partners comprised the Food and Agriculture Organization of the United Nations (FAO), the National Coordination of Indigenous Peoples of Panama (COONAPIP), the Ministry of Environment of Panama (MIAMBIENTE), the Rainforest Foundation (United States) and the indigenous communities of Panama.

FAO is the main partner of the community forest monitoring project, providing technical assistance and practical training and supporting the indigenous communities.

The National Coordination of Indigenous Peoples of Panama (COONAPIP) coordinates eleven general congresses, including four indigenous districts in the Republic of Panama and actively participates in the country's economic, social, cultural and environmental policies, contributing to the collective and multicultural aspiration of indigenous peoples in the country. Its work focuses on the legalization of indigenous territories and the indigenous economy, among other functions. The role of COONAPIP was key to this project as it initiated the project proposal with FAO and requested funds from UN-REDD through the Ministry of Environment to carry out community monitoring.

COONAPIP also had the responsibility of liaising between the project team and the indigenous peoples, as well as helping to coordinate and communicate with the traditional authorities. All activities were organized through COONAPIP, who in turn acted as interlocutors with the traditional authorities if a problem arose.

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The Ministry of Environment of Panama (MIAMBIENTE) liaised between the project team and the National Forest Monitoring System, supported the training activities and its officials attended the academic courses that were arranged.

The Rainforest Foundation (United States of America) supports communities in developing processes to resolve conflicts over land tenure, reporting illegal logging by timber companies, managing forests and protecting the environment. Globally, the Foundation develops campaigns to influence national and international laws to protect rainforests and their inhabitants. In this project the Foundation supported communities with territorial management scaling with management plans.

Local communities, traditional authorities and indigenous technicians were placed at the heart of the project and, through COONAPIP, were involved in all aspects of it. Traditional authorities appointed technicians, supported activities and incorporated community monitoring into their worldview. The indigenous technicians were the key players in the implementation and success of the project.


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The community forest monitoring project began in 2015 and was extended to 2017, which allowed activities to be expanded to more communities and, at the same time, the exchange of experiences with other countries to be organized. The first drone flight took place in April 2016, in the Madugandi Comarca community. Since then, more communities have joined, and by June 2017 the 12 indigenous territories of all ethnic groups in the Republic of Panama (Bribri, Bugle, Emberá, Kuna, Naso, Ngäbe, and Wounaan) had joined. During 2017 there have been exchanges of experiences with the Republic of Guatemala, the Republic of Paraguay, the Republic of Colombia and the Republic of Peru.

Context and problems raised

In 1950, approximately 70 percent of the Panamanian territory was covered with forests (5.3 million hectares). In 2012 this figure fell to 60 percent of the area (4.5 million hectares). According to FAO's 2015 Global Forest Resources Assessment, between 2010 and 2015, 16 400 hectares of forest per year were lost (equivalent to 90 000 soccer fields per year). Deforestation and the loss of ecosystem services associated with forests represent the loss of natural capital from which the livelihoods of local communities and indigenous peoples derive. This implies a close relationship between deforestation and food insecurity, a risk that is increased by the poverty conditions that in general affect this segment of the population. Forests cover more than half of the Panamanian territory and indigenous peoples, the main inhabitants of these areas, play a vital role in the care and monitoring of this important resource for food security.

The Republic of Panama is advancing in the development of the National REDD+ Strategy. As part of the joint UN-REDD national programme, work was done on the design of a National Forest Monitoring System (SNMB).[2] The SNMB was defined as a multipurpose system that provides key information for REDD+ and for the monitoring of forest resources in general. In this context and complementary to the SNMB, a project was carried out for the community management and monitoring of forests in indigenous territories, supported by resources from the UN-REDD programme through FAO, in conjunction COONAPIP and

[2] The development of the SNMB was part of the joint national programme. FAO provided the methodologies, the satellite system, the forest inventory and the geoportal to give it visibility and transparency. The SNMB is still under development and in the process of institutionalization in MIAMBIENTE.

the Ministry of Environment of Panama (MIAMBIENTE). Based on this project, personnel of eleven of the twelve congresses and indigenous councils of the country were trained in the use of drones. The training included the preparation of flight plans, arming and manoeuvring drones, image processing and mapping with high-resolution images.

The main objectives of the forest monitoring project were to identify changes in specific points of forest cover undergoing deforestation and degradation processes, to monitor the status of crops and to monitor invasions of territory. The maps generated enable the authorities to guide decision making for the protection, management and conservation of their forests and natural resources, thus contributing to Sustainable Development Goals 13 and 15 linked to ecosystem and climate change.

The technicians were also prepared for the development of forest and carbon inventories, to generate databases on their forest resources so that, later on, they could implement a community intellectual property protocol on traditional knowledge of flora species.

Currently there are seven monitoring stations operating in the different indigenous communities of the country, coordinated by young indigenous technicians who form a community forest monitoring network, which favours the exchange of experiences between territories and technicians, thus promoting learning among its members.

Community forest monitoring aims to improve the management and conservation of natural resources in indigenous territories by:

- capacity development of indigenous technicians in the areas of remote sensing of geographic information systems (GIS) and forest and carbon inventories;
- generation of geo-referenced information among the different indigenous territories, using a standardized methodology and, at the same time, serving the specific needs of each territory; and
- standardization of the storage of remote sensing data at different scales and processing of field-collected information that is reliable and truthful.

Implementation of the project and development of technical tools

The project on community-based forest monitoring of indigenous territories included the following activities:

1. introductory training for indigenous technicians in Geographic Information Systems (GIS), remote sensing for forest monitoring and use of data servers;
2. acquisition of monitoring stations for the storage of geo-referenced data and remote sensors for community monitoring of forests, for some indigenous congresses and councils;
3. drafting of the first draft of the community intellectual property protocol on traditional knowledge of flora species and collecting reference plant material in indigenous territories;[3]
4. development of a database for forest inventories; and
5. training on methodology and measurements for the National Forest and Carbon Inventory of Panama (INFC) and collection of forest data in indigenous territories.

Community forest monitoring, in a descriptive context, provides information on the different natural resources, biodiversity and health of the environment. In addition, community monitoring should obtain information that is of interest to the communities and territories involved. This information collected in the territories can provide data for the National System of Forest Monitoring. However, certain steps should be taken to ensure Free, Prior Informed Consent (FPIC)[4] for the exchange of information at each level.

The proper management of forest land and the protection of natural resources and ecosystems of indigenous communities can only be achieved through the knowledge they have about their territory at local level. Community forest monitoring allows the communities themselves to lead the collection and analysis of information, according to the particular interests of each community and territory.

Through continuous monitoring at territorial and local levels it is possible to determine if there are changes in forest ecosystems. The combination of terrestrial and remote sensing monitoring allows scientists and others to know the dynamics of loss, degradation and restoration of the forest cover. The results of these analyses support decision-making

[3] **Community Intellectual property protocol**. As part of the National Forest Inventory, there is a need to collect reference plant materials in indigenous territories. In general, several projects have gone to these communities to collect plants in their territories and use indigenous genetic resources. To protect itself, the communities demanded an indigenous lawyer to develop a draft in community intellectual property protocol, through a participatory process, which aims to protect communities and reconcile their demands. This experience turned out to be a great learning experience for everyone involved.

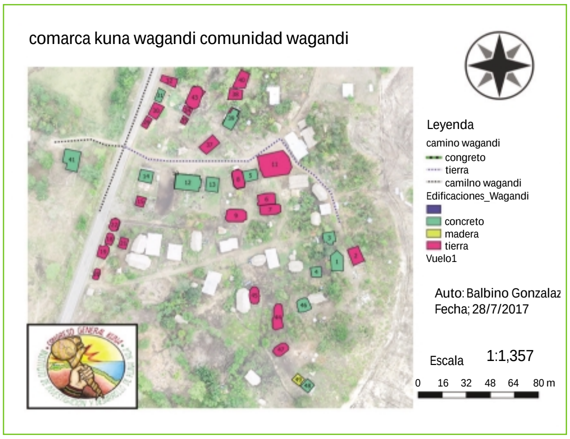
[4] **Free, Prior and Informed Consent** (FPIC) is an internationally accepted principle of sustainable development, which recognizes that it is desirable to open a consultation process, through which a community potentially affected by a project is involved in an open process and informed dialogue with individuals and persons interested in following the activities in the area or areas traditionally occupied or used by the affected community. The need for consent covers all issues related to the life of indigenous peoples, as it is an extrinsic right to the exercise of the right to self-determination and a basic component of the right to land, territories and resources.

(by the way of congresses, indigenous councils and local authorities) on desired actions for the conservation and sustainable management of resources in their territories, in favour of the well-being of the communities. This knowledge about the situation and dynamics of forests in indigenous territories, a product of community monitoring, is also an important complement to the National Forest Monitoring System (SNMB).

In this sense, it was necessary to establish a conceptual framework that establishes the duties and coordination among the actors involved and defines the components, basic infrastructure and other requirements for sustaining the community forest monitoring system. The three levels of monitoring – congresses and councils, indigenous territories and national territory – are based on a technological infrastructure and technical capabilities developed that integrate local knowledge with the technical and scientific bases of forest monitoring. The conceptual framework was developed in a participatory manner with the support of all stakeholders.

With respect to technological infrastructure, a network of monitoring stations equipped with adequate physical equipment was installed and this will be extended to the extent that more resources are allocated for operation and maintenance. As an initial investment, one central station and six monitoring stations have been installed in different indigenous territories of the country, where all the information generated by the monitoring system is stored and administered and the dedicated resources are housed to process this information.

Community forest monitoring also brings technical capacity development in the communities, as it involves the active participation of local staff with varying degrees of knowledge, professional training and roles. The technicians who are endorsed by the different participating indigenous congresses and councils have received the technical training necessary to carry out measurements/observations of forest inventories and the collection of forest data for terrestrial monitoring within their own territories; monitoring by remote sensing with satellite images and aerial photographs obtained with drones and the use of GIS for the generation and management of monitoring system information.



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1. Open source software used by the project

The different types of open source software used to obtain information for the project are listed in Table I1.

Table I1. Open source software used to obtain information	
Tool	**Description**
QGIS	Desktop GIS software to visualize, create, edit, manage and analyse spatial data, besides creating maps and other cartographic products.
Google Earth Pro	Desktop software to visualize spatial data, satellite images and maps, produce 3D images and videos for presentations and reports.
Google Earth Engine	Online platform for the visualization of geospatial data and large-scale scientific analysis of large datasets. Contains historical series of satellite images.
RealFlight	Drone flights simulator for the learning and practice of flight manoeuvres with multiple aircraft models, useful to improve technicians' skills for drone flights.
Mission Planner	Open source software to direct the RPA ground control station (drones): schedules flight missions, monitors the state of the aircraft in operation, and generates telemetry records.
Open Data Kit – ODK	Free open source toolset for mobile data collection: develops data capture forms, collects data from mobile devices and manages them on a server.
PostgresQL / PostGIS	Open source software for object-relational database management, with an extension – PostGIS – for spatial databases.
Geoserver	Open source software to share geospatial data from different sources as geoprocessing services, using open geographic information standards such as Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS), among others.

2. Geo-referenced database

A geo-referenced database with satellite information and forest inventories was also used. The database consolidates the information generated by the various components, allowing the input of satellite and terrestrial data. The database provides information for natural resource management processes and allows the cross-referencing of data and the making of more accurate comparisons.

Some of the objectives to be considered are the stabilization, security and integrity of data management. This methodology, besides achieving the standardization or uniformity of the use of centralized information – both local and national – will give an analysis of the data suitable for feedback to the communities.

Community monitoring centres will have the potential to collect information based on other variables, such as:

- biophysical variables;
- socio-economic variables (occupation of territory, products, use of goods and services, beneficiaries, etc.);
- cultural variables;
- generation of community alerts: with the inputs provided in the satellite monitoring and the database, reports can be made to generate community alerts that improve the management of the territory; and
- usage plans.

The collection should follow the guidelines of the Intellectual Property Protocol, coordinating actions with local community authorities, designated technicians and involving users of forests.

3. Drones

The information generated by drone flights can have multiple applications and can be used for different purposes, depending on the requirements of each community. This would include forest monitoring, territorial planning, monitoring of forest fires, population growth dynamics, invasion of their territories and monitoring of crops, among others.

In addition to obtaining images of very high spatial resolution, the high superposition of images obtained with the drones allows the derivation of height data, from a digital stereoscopy.

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With this information on the height and the ground cover, the altitude and the volume of the vegetation can be calculated and, together with the land points, the necessary topographic information can be gathered. Through the multitemporal analysis of these results, very subtle coverage changes, such as the extraction of a particular tree, can be identified in an automated way.

This technology, as a whole, allows the consolidation of a surveillance system in areas with active dynamics, as it will provide information in real time, reliable, easy to process and practically independent of climatic conditions, which allows:

1. monitoring of areas with continuous cloud permanence;
2. economically efficient monitoring of inaccessible areas and/or areas with little visual coverage;
3. easy learning and generation of reliable results;
4. empowering communities to use the tool from their own capacities, since it can be monitored when needed; and
5. optimizing surveillance: the evidence gathered can be useful for legal proceedings.

The drone model chosen for this project is the “Fixed-wing drone model E384” from Event 38 Unmanned Systems. This model was chosen for being easy to use, easy to repair and very light, and can cover long distances in a single flight. This model also makes it possible to carry out, specifically, flight plans and post-processing for the monitoring of the earth.

Fixed wing equipment, model E384

This equipment is designed for photogrammetry and mapping applications and its main features are listed in Table I2.

Table I2. Characteristics of the E384 model

Physical characteristics	Operational characteristics
Dimensions: 71" (180 cm) width of wings 51" (129 cm) long	Cruising speed: 27 mph (44 km / h)
Weight: 5 lb (2.3 kg)	Flight time: 100 to 120 minutes
Maximum load capacity: 2.2 lb (1 kg)	Range: 40 to 54 miles (64 to 85 km)
Flight battery: 4 cells, 8.0 Ah	Climate: autonomous operation up to 25 mph (40 km/h)
Pixhawk autopilot, includes GPS	Modes of operation: assisted, automatic and autonomous mode
Remote control: Spektrum DX5e	Real-time telemetry station on a laptop up to 10 km
Telemetry options: 433 MHz and 915 MHz	Maps up to 960 acres (3.8 km^2) per flight of 5 cm/pixel
Wings and body can be assembled for easy portability	Automatic camera control Canon S100 12.1 MP

In general, it is argued that the use of drones has the following advantages and disadvantages:

Advantages

1. obtaining very high-resolution images in areas of high cloudiness (illegal logging does not wait for sunny days or some satellite to pass);
2. lower cost than a field visit in large areas, in addition to generating an indisputable result and easy interpretation to convey what is happening;
3. reduction of time: the data capture occurs at the moment and the storage capacity of the equipment allows its subsequent analysis;
4. increased staff safety – it is not necessary to cross thousands of hectares in a day, nor to fly over areas with the risk that this implies; and
5. accessibility – areas that, because of their orography, are difficult to study can be accessed with the equipment.

Disadvantages

1. it is more expensive to use a drone and to buy all the equipment than to use satellite images – as images are not available for this function, the use of the drone is the only existing alternative;

2. being a dynamic three point of reference system (the user, the controller and the drone), the temporal reaction in the execution of actions can become conditioned, which could generate a delay between the emission and the execution of those actions, affecting the team if the conditions are not adequate;
3. the acquisition requires initial investment and the maintenance of the equipment needs fixed personnel, specifically formed to use it appropriately; and
4. new regulatory standards will define the use of drones in the national territory and these will require updating.

To carry out the flights it is necessary to follow the protocol established in the prepared forms: pre-flight/post-flight checklist and take-off supervision, documents detailing the procedures for:

- Preparing the equipment
  - verification of all equipment required for drone missions, using the pre-flight/post-flight checklist;
  - battery charge – battery charger programmer (Lipro balance charger) for aircraft batteries (8 000 ap) at 5 volts, camera battery charge and transmitter or control batteries;
  - internal connections – connection of telemetry cables, drone battery, camera and autopilot system (Pixhawk); and
  - assembly of the drone – assembly of fuselage, tail and elevator, wings, elastic bands to fix, camera, cable connections, battery of the drone and, finally, the motor propeller.

- Connection to telemetry and flight mission planning

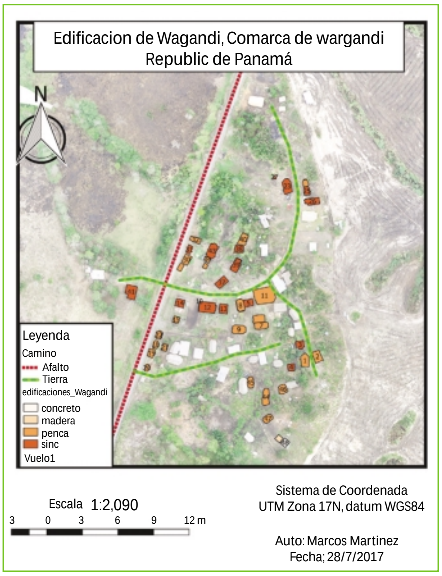
To elaborate the flight plans it is necessary to:

- prepare the laptop computer by connecting the telemetry modem to the USB port, then connect to the E384 from the E38 Mission Planner software; and
- create the flight plan – search the site of interest, create the polygon of the area to be flown and generate flight lines based on parameters such as camera, flight altitude, desired resolution of images, 60 percent photo overlap (recommended), available battery time and others. The *Mission Planner* manual describes in detail the procedures to follow with the application.

4. Equipment for collecting forest information

For terrestrial data collection, an application is used to identify newly cleared lands and to find areas identified during previous flights.

The application can be installed on a smartphone, since its use is quite common in indigenous communities and all technicians have one. Other applications used allow adjustments, depending on the needs of the project. For example, some allow you to make a field form to collect the data in the field. They are free access applications that technicians can download and use on their own mobile devices.



Project impact

In the Republic of Panama, the monitoring component of forests in indigenous communities has greatly aided global monitoring and has helped meet the demands of the REDD programme at the national level. It should be noted that those areas of the forests that belonged to indigenous territories had not been covered by pre-project monitoring.

An important component of the initiative was the emphasis on capacity development. Indigenous communities have been trained in the use of drones and other technologies to monitor changes in land use and coverage of all areas. With these technologies, they have been able to generate very precise data that help them to make decisions and manage their territory.

Communities can use data and information to halt and report illegal logging operations, but also to monitor fires, harvest crops, water resources, etc. The use of the data depends on the decisions of the indigenous authorities. Since they use the data independently, each territory uses the technical tools according to their own needs.

After the training of the technicians, they have applied their knowledge for other purposes complementary to the monitoring of forests. There are pilots for community forestry and other more practical functions that are needed and, in some cases, provide economic support. Nowadays, the technicians support several local actions, such as the identification of areas of fire that also can be located with the drones or with free satellite images.

Many communities want to acquire their land tenure rights and for this the technicians have helped to implement the field survey and to design the maps. The trained technicians use the tools and their new GIS capabilities to develop maps that support them in preparing demands for land rights, which will be submitted to the government. They themselves outline it with the members of their community and coordinate directly with COONAPIP. The documents for obtaining tenure rights of five territories are already being evaluated by the competent national authorities.

The training has also transformed the dynamics within indigenous communities. After the project, its members are more empowered to bring problems forward and to develop proposals and to prepare high-quality technical reports that are very supportive of traditional decision-making authorities. Although the focus at the beginning of the project was forest monitoring, the people involved are already applying the tools for other needs in their territories.

Indigenous technicians actively participated, incorporating what has been learned to the realities of their territories, which will contribute to improving the management of their forest resources, while maintaining their traditional knowledge. They have also encouraged the exchange of experiences between territories through the technicians, which has promoted learning among them. Their participation in different training events has strengthened their knowledge in the monitoring of forests and has strengthened the relationship between them. They are the ones to lead the discussion on community monitoring issues with the authorities. Recently they started the initiative “Geo Indigena”(Geo Indigena, 2018), a platform of services they can provide to the different authorities to support sustainable development of the territories.

Innovation and success factors

Thanks to the use of drones and new technologies, community monitoring of forests has been transformed positively. With the new knowledge and equipment available, communities can generate very accurate data that help them make decisions and manage their territory, and extend the range of areas that can be monitored. But beyond technology, it has been the people involved in the project who are responsible for the success of the project.

The practice has had positive results thanks to the close collaboration with COONAPIP and the technicians chosen by the traditional authorities of the indigenous territories. The project was designed for them and, at all times, adapted to the needs and demands of the communities. Its members not only participated in the process, but also directed it and that is where the success of the project resides. Those involved wanted to do the work for themselves and thanks to their motivation they managed to make the proposals work. It is clear that communities want to empower themselves and not only participate, but also to organize the workshops.

It is worth mentioning that, thanks to the mediation of COONAPIP, each community was able to choose at least one technician to work with the authority corresponding to their territory.

To achieve these results, it was very important to have a holistic vision to guide the actions and activities developed. The introduction of new technologies was only a small part of the process, since training has also favoured and stimulated creativity in the use and application of new knowledge and technologies to solve the technicians’ own needs and to benefit their communities. The project introduced a number of innovations, for example, constant feedback between technicians and their authorities, strengthening the processes of internal governance of communities, which was essential to the success of the project.

Limitations

During the activities, there was an unanticipated limitation related to the participation of women in training activities. At first there were women participating in the training, but at the end of the activities they had stopped attending. So far we have not identified the specific reasons why women left the project and how we could have reversed the situation. What is clear is that the gender approach in the project was poorly developed and this should be prioritized in future actions. For example, through the Voluntary Guidelines on Responsible Governance of Tenure, which mentions the removal of obstacles to the rights of indigenous women as one of the keys to success for sustainable governance of natural resources.

Moreover, the selection of the technicians created several obstacles: they were selected by the authorities of the territories and the selection criteria were very varied and, in some cases, they did not take into account certain basic needs – for example, the need for the technician to have an email account – and that complicated the process at various stages of the training.

The project also presented some challenges related to the forest monitoring system, such as:

- system sustainability;
- credibility of the information generated at community level for the national authorities;
- comparability of information; and
- incorporation into the National Forest Monitoring System and Nationally Determined Contributions (NDC).

Lessons learned

In general, there was no cultural resistance to the implementation of the project since at each stage, through the COONAPIP, the indigenous authorities were consulted and involved. The same proposal came from a joint effort with the authorities, which recognized that new technologies could favour forest monitoring and thus strengthen forest governance and land tenure. Currently, there are capacities created within communities in database management and geographic information systems to generate maps of territories, remote sensing with high-resolution images and low-resolution images and collection of forest information.

From this project, we can also draw a significant lesson on the importance of the partner COONAPIP. During the process, the institution was the initial driver and focus at each stage of the project and the link between all the parties involved. They also supported the Free, Prior and Informed Consent (FPIC) process before starting any activity in indigenous communities. Sometimes, the authorities did not fully understand the objectives of the project and opposed its implementation. The dialogue, facilitated by the Coordinator, was very important to adapt the activities to their wishes and needs.

Indigenous technicians also played a key role in the project. A bond and a network have been created, after having conducted various activities throughout the year. They know each other better, continue with the exchanges and support each other thanks to the regularity of the meetings. The indigenous technicians are those who have the trust of the indigenous authorities and were chosen by them. Therefore, they also play an important role in the dialogue and adaptation of activities during the process.

At the end of the project, the team believes that government participation should be strengthened, which will contribute in the future to integration with the national monitoring system. Moreover, strategic alliances and the identification of new relevant actors could be strengthened in order to make more efficient use of available funds and broaden the scope of actions.

The continuity of the project with different sources of funding created a favourable environment for the understanding and dialogue among stakeholders to identify issues in their territories. The technicians have put all their energies into ensuring the project's success, which has allowed the adaptation and improvement of activities to manage their natural resources during the process.

Sustainability

Global experience is contributing to environmental sustainability, however, there are some issues regarding sustainability in relation to the use of ICTs and drones to be taken into account.

Over time, the drones will be damaged and at the end of their useful life they will have to be replaced. In order to reduce costs, the project is testing a cheaper type of drone, always considering open source alternatives.

Moreover, most trained technicians are volunteers and much of the work is done and managed at the community level, which avoids financial dependence on projects. But the cost of field missions is quite high and it is not always easy for communities to continue with the work.

In order to strengthen the sustainability of the project, a national indigenous forest monitoring network was created for the time being composed of 17 members, with at least one representative from Congress.

To ensure greater sustainability, several alternatives can be considered, for example:

1) incorporate community monitoring into the Ministry of Environment to receive long-term support and to propose a definitive component of monitoring at the national level; and

2) incorporate monitoring into the costs of forest resources utilization through the management plans.

Project replicability appears to show promise and clearly the project has had some important successes in terms of its technical and ecological goals, but it is important to acknowledge the profound way that it has affected indigenous communities. Eliceo Quintero, a young indigenous person from the Ngäbe Buglé Comarca, a participant in the project, emphasized how interesting the experience has been thanks to its many levels of innovation:

> These tools allow us to know the characteristics of the forests and the resources we have in our territories. Training has been carried out to analyse geographic information and use of technology tools in the field, with direct applications in the forests.

Eliceo Quintero adds that the data they have collected have been interesting because they have helped them discover some of the unique characteristics of the development of the species in the area:

> We have identified local native species, analysed the forest cover, how the impact of deforestation has changed and it has been useful to us to discover some interesting places and sacred sites. It has also allowed us to test the levels of organization of the community and strengthen the administrative management of our authorities.

On the future of this initiative, young people aspire to seek more instruments to expand their reach and to generate a community monitoring network at national level, a valuable contribution to their efforts to monitor and protect their resources, to rehabilitate degraded areas and to manage their resources for future generations.

References

Geo Indigena. 2018. Nuestra aporte tecnologico ancestral [online]. [Cited March 1st, 2018]. www.geoindigena.org

For more information

Maricarmen Ruiz Jaen
Technical Advisor on community-based forestry and monitoring and part of the REDD+Team at FAO
maria.ruiz@fao.org

Lucio Santos – FAO Forestry Officer and part of the REDD+Team at FAO
lucio.santos@fao.org

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kailash kumar from Pexels

Case study

J

Internet of things application in agriculture and use of unmanned aerial vehicles (UAVs)

EXPERIENCES FROM CHINA

Photo by Quangpraha from Pixabay

Introduction

Ensuring the health of the rural economy has been one of the world's most challenging issues. In the more developed countries, the Internet of things (IoT) has been employed to benefit farmers, increase production and reduce operating costs as well as to enhance labour efficiency, but it is still out of reach for most developing countries. In recent years, the IoT has made remarkable progress and is regarded as the most promising technology for propelling agriculture, i.e. farming, fishing and the poultry industry, into the future. However, there are no base stations and Wi-Fi stations in most farming areas, which prevent the application of the IoT in agriculture. In this chapter, an unmanned aerial vehicle (UAV)-wireless sensor network (WSN) based system that has been applied in the rural area in the People's Republic of China to resolve this issue will be demonstrated.

The role of surveillance in agriculture shows great promise such as in biological disaster prevention in forestry and farm plant protection, fisheries etc. Therefore, low cost, real time, large scale and stable surveillance, accurate data acquisition and transmission as well as processing are very crucial for agriculture production and disaster prevention. However, in most rural areas the absence of wireless base stations and Wi-Fi stations is a major obstacle in implementing surveillance systems. That means the data acquired through the Wireless Sensor Network (WSN) cannot be transmitted using wireless communications. An alternative solution is to employ UAV to communicate with the WSN in large areas to get real time data for processing and analysis.

UAV-WSN based system and application

In this project, UAV-WSN based systems were developed and applied in several farms in the People's Republic of China, including farmlands based in Baoan, Longgang and Yantian districts, Shenzhen in Guangdong Province.

This project has been supported by the following partners:

- Shenzhen Agriculture Technology Research Centre
- Shenzhen Nopoison Agrochemicals Co., Ltd., the largest fertilizer provider in the country
- D-Tech (Xintai) Technology Co. Ltd., Xintai County, Taian City, Shandong Province
- Shenzhen Economy and Trade Information Committee, funding provider

This practice was implemented on the farmlands belonging to Shenzhen Agriculture Technology Research Centre, Shenzhen, Shenzhen Nopoison Agrochemicals Co., Ltd. and other corporations, beginning in 2017.

The initial situation with respect to surveillance on the farms was that there was no base station, no Wi-Fi station nearby or the signals were too weak for communication. Thus, farmers needed to spend significant time on farm data acquisition and had no access to real time farm information. This situation is very undesirable when encountering, for example, weather disasters, high temperatures, oxygen and poisonous material or polluted water, as these will destroy crops before any action can be taken.

In this case, it was feasible to install both Zigbee and Lora wireless modules in the UAV. Meanwhile, the Zigbee or Lora technique based on a wireless sensor network was applied on the farm to communicate with the module in the UAV. More than 30 wireless nodes were applied (Figures J1 and J2). The conventional technology is to apply mobile communications such as the GPRS or the third or fourth generation of mobile communications (3G or 4G). However, as there was no base station, no Wi-Fi station or very weak and unstable signals on farmlands it was hard to transmit the data acquired to the farmers' control centre.

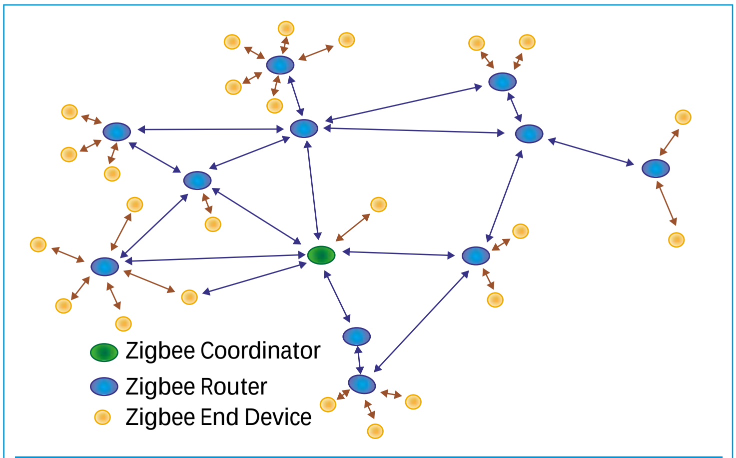


Figure J1. Large-scale wireless sensor network communication

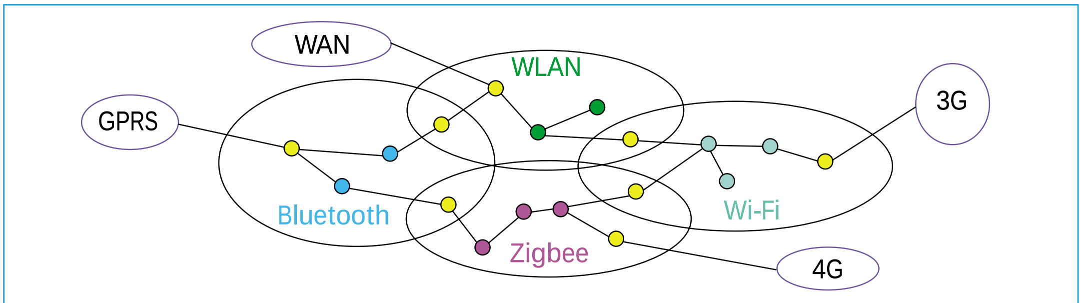


Figure J2. Heterogeneous network and multiple modular fusion and efficient interface control

This smart network system employs 3G or 4G mobile communication, GPS, 3D GIS, that is wireless sensor network (WSN) mesh technology. The WSN network is a blend of sensors embedded processing, distributed information, wireless communication, network security, intelligent control and a series of advanced technologies of the Internet of things technology platform.

Using a complex comprehensive system

The UAV-based WSN scheme comprises one complex comprehensive system, which closely integrates the above techniques. This means that if any of these techniques are missing this scheme will not be successful.

Figure J3 shows the data that was acquired using serial port communication with the UAV. After the data was acquired, it was saved on an SD card for communication through a serial port.

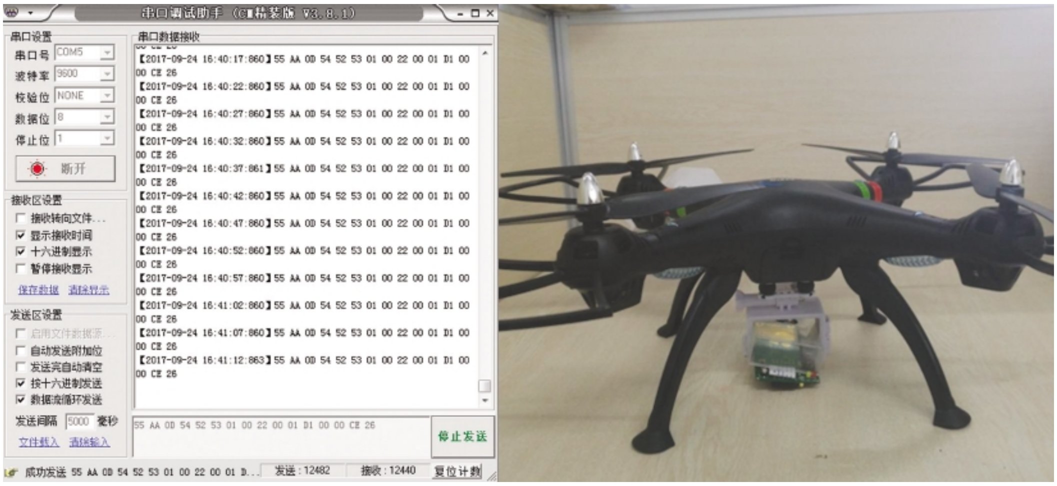


Figure J3. Data acquired with UAV

Figure J4 shows the diagram of the UAV-WSN system. In this figure, there are WSN networks that combine dozens of Zigbee nodes that are connected to sensor modules, and which then communicate with the UAV that is equipped with one Zigbee node.

Each Zigbee node can cover a radius of 200 m to 500 m of land thus dozens of nodes can actually cover about 1 000 to 2 000 acres of farm. Each sensor module consists of up to ten sensors for soil and environment information, for example soil temperature, soil humidity, soil fertilizer, sunlight intensity, CO_2, soil PH value, rain intensity, wind intensity. The data acquired will then be transmitted from the coordinator inside the WSN to the UAV side for data collection.

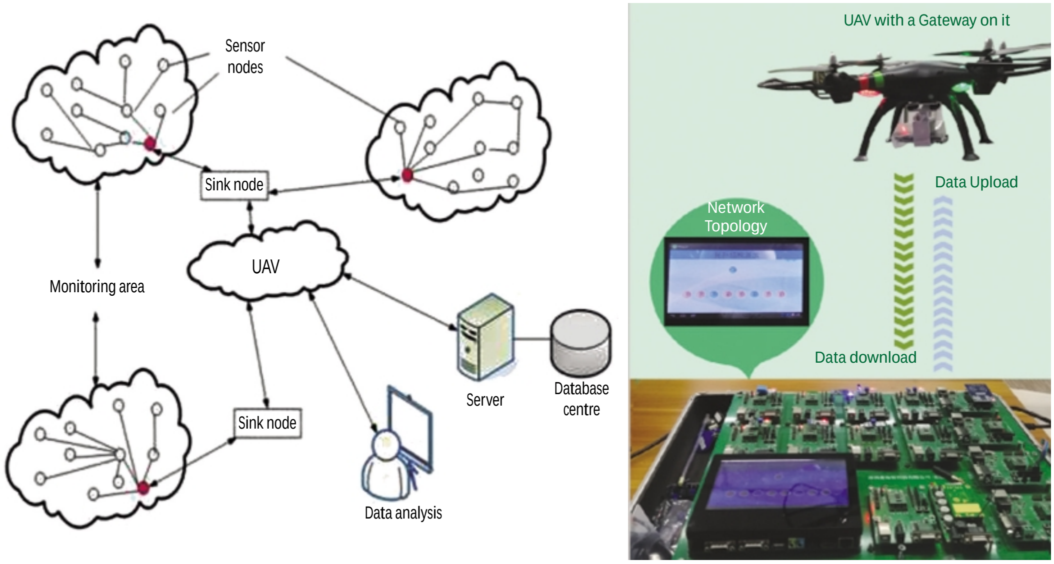


Figure J4. Diagram of the UAV-WSN system

The parameters of the UAV in this chapter are described in Table J1. The performance of the UAV is affected by various factors, which will be determined regarding the performance to cost ratio.

Table J1. parameters of the UAV

Functionality	Performance
1 Climbing speed	5 m/s
2 Cruising speed	12 m/s
3 Maximum power	800 W
4 Body weight	2 650 g
5 Task reload	600 g (recommended)
6 Task reload	1 600 g (maximum)
7 Flight weight	5 000 g (maximum)
8 Body size	700 mm (wing distance opposite angle)
9 Flight time	<30 minutes/per battery block
10 Working humidity	80%
11 Wind resistance ability	10 m/sec
12 Rain resistance ability	Heavy rain
13 Flight radius	600 m
14 Flight height	600 m

Table J2 shows the comparison of benefits between the conventional system and the UVA-WSN based system.

Table J2. Benefits analysis

The expenses of Infrastructures of the IoT with an area of 100 acres: CNY 100 000. The annual cost of system operation and maintenance: CNY 12 000.	
Merits	**Saving expenses**
Through measuring related parameters by the UAV-WSN scheme, water resources can be saved significantly by accurate irrigation.	Compared to conventional irrigation, the UAV-WSN based scheme can save water resources by up to 67 percent.
Savings in human resource expenses, i.e. reducing workforce by one management staff and one worker.	Saving human resource expenses of CNY 100 000 annually.
Compared to the conventional method, the UAV-WSN scheme can reduce wastage of chemical fertilizer as well as reduce soil pollution dramatically by more accurately measuring the rate of mixing pesticide, chemical fertilizer and water.	Saving water and chemical fertilizer expenses of CNY 3 000 and increase fertilizer utilization rate by up to 40 percent annually.
Improves farm live rate and reduces growth period as well as improves product volume significantly.	Farm crops live rate can be improved from 20% to 80%, growth period reduced by up to 30% and production volume improved 1.5 to 2 times.
Improves labour efficiency significantly and reduces labour intensity. In addition, farmers no longer need to spend significant time on the farms and can spend more time at home or for farm management.	This application can get back the UAV-WSN investment and gain profits within one year.
Traditional agriculture	**UAV-WSN system based agriculture**
The farmer gets limited farmland information mainly through the senses and the process is time-consuming and not in real time. Agricultural production mainly relies on humans, livestock, machinery. Large-scale production capacity is low and there is a lack of unified standards and procedures.  	By using UAV and wireless sensor network the farmers can quickly obtain data on farmland environment real-time with high degree of accuracy. Information collected from the sensor network is transmitted to the UAV for further processing in a control centre. Analysis can be real-time, precise, large-scale, automated and controllable.  

Application

- The first application was an area totalling 12 000 acres, with about 500 acres of vegetable and pepper shown in the CAD map of the farm in Figure J5. WSN and UAV have been equipped in these farm and will be covering all of these areas. This farm is located in Xintai, Shandong Province, and this scheme has been sponsored by the D-Tech (Xintai) Technology Co., Ltd., Shandong Province.

Figures J6 and J7 show the data acquisition platform that receives the data from the UAV to determine whether the control centre needs to control spraying, irrigation or integration of water and fertilizer.

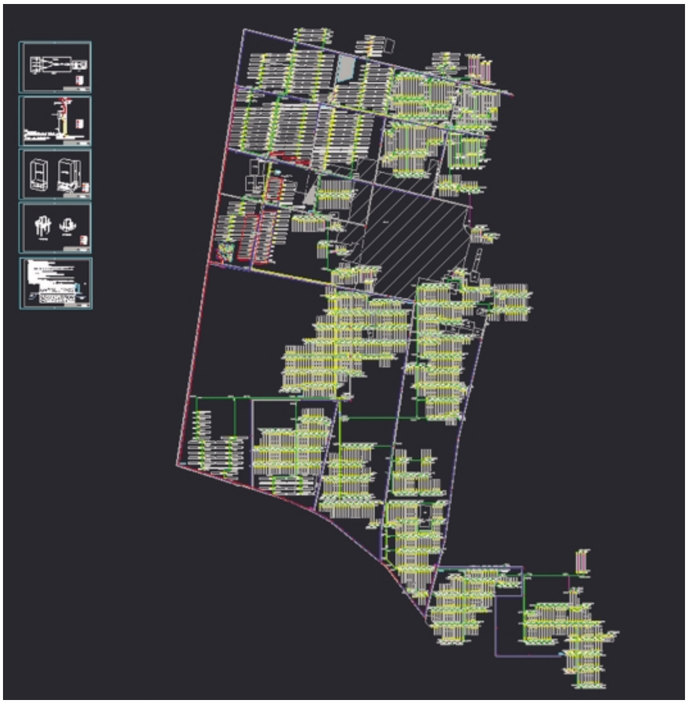


Figure J5. The CAD map of the farm in the Wenshan, Yunnan, China

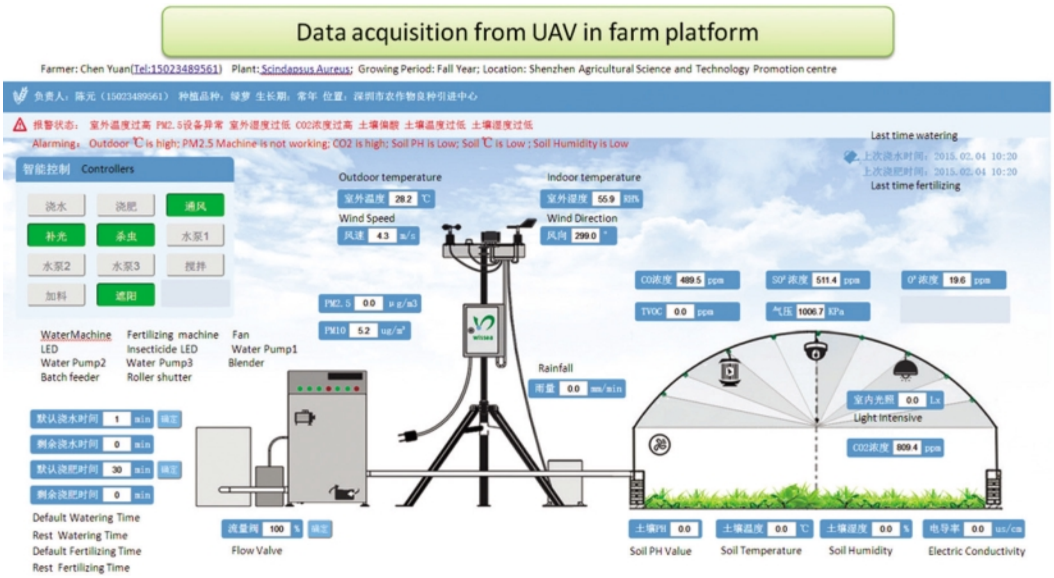


Figure J6. Data processing and analysis as well as equipment control

Figure J7. Data acquisition platform

Challenges

One of the challenges is the balance between the UAV cost and the performance. High performance of the UAV with long flight time, stability, as well as limited interference will be expensive and prevent farmers from adopting the application as they are very resistant to any new costs. The second challenge is that farmers need time to accept new technology and to be convinced that profits from this scheme are guaranteed.

Lessons learned

These UAV-based techniques will improve farm production efficiency significantly with more and more applications, which have shown remarkable improvements for large farm data acquisition compared to conventional farm surveillance. However, the UAV-based surveillance still has to meet challenges such as stability in poor environmental and weather conditions. Therefore, the UAV-based WSN is a promising technology and an alternative that will achieve low-cost, wide-ranging communication, real time, reliable data acquisition when the base station is not available.

Sustainability, replicability and upscaling

This scheme and practice has attracted both government-based and private farm enterprises, as both of them are encountering smaller farm populations, often in remote areas, and have a need for wide ranging surveillance related to farming conditions. More accurate soil and water information and information on weather conditions are increasingly crucial to farmers. The performance cost ratio of this scheme is appropriate for farmers. This scheme meets the environmental conditions on medium or large farmlands far from a control centre and without a base station or with a base station where the signal is weak. This practice has been replicated on several farmlands as most cases are similar and this scheme meets current farm information surveillance requirements making it an excellent alternative to conventional network systems. The next step is to improve the performance of UAV-WSN on low sensor power consumption, long time flight battery, and to mitigate interference from wireless communications, etc. Large-scale replicability and upscaling of the UAV-WSN technology application will be possible when these issues are resolved.

Conclusion

If this UAV-WSN based surveillance system is applied widely in the near future, millions of farmers will be able to benefit from the acquisition of real time farm information. Farmers will not need to spend a significant amount of time on acquiring farm data and will have access to disaster warning and weather information when a disaster event seems possible. Nevertheless, the UAV-WSN technology is still not mature enough for large-scale application. More UAV-WSN research and development work is required, including the development of applications for fishing, poultry and farming enterprises.

Bibliography

Baránek, R. & Solc, F. 2012. Modelling and control of a hexa-copter, pp. 19–23. Proceedings of the 13th International Carpathian Control Conference (ICCC), 28–31 May. [online]. http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=6222116

DJI. 2017. Smarter agriculture package. [online]. http://www.precisionhawk.com/agriculture

Wang, J. (May 2014). The design of 'Six rotor UAV model of Agriculture'. (Translated from the Chinese). [online]. [Cited 23 Sep 2017]. http://www.taodocs.com/p-23157432.html

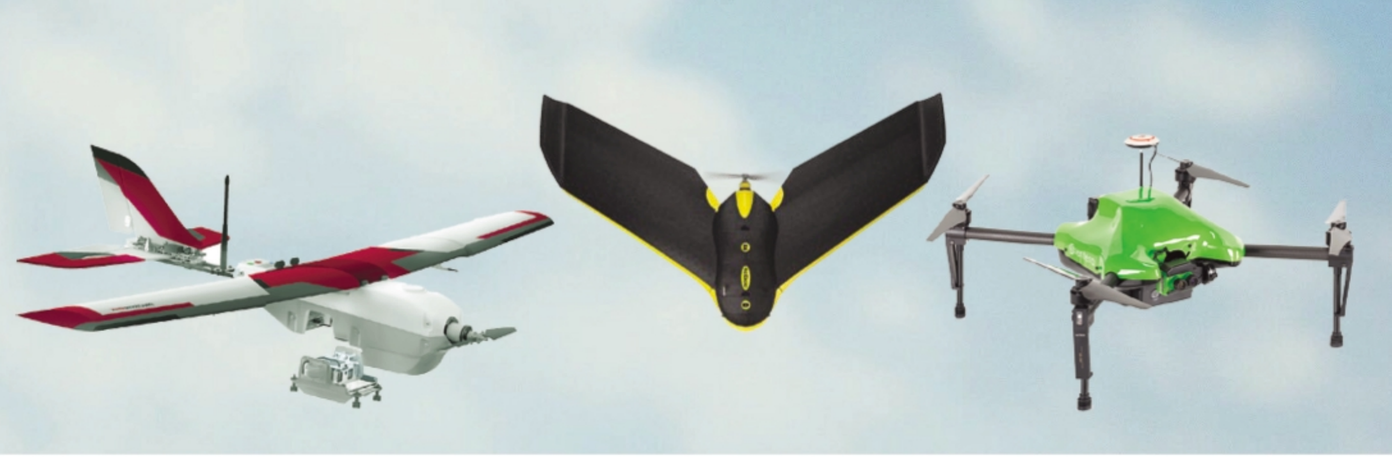
Yin, W., Zhang, J.N., Xiao, Yu, M.Y.P., He, Y.H. 2017. Application of the Internet of things in agriculture. *E-Agriculture in action*, pp. 81–85. Bangkok, FAO and ITA.

Zhang, Z., Cui, T.S., Liu, X.F., Zhang, Z.C., & Feng, Z.Y. 2017. The design and implementation of 'the use of UVA in agricultural ground surveillance system'. *Journal of Agricultural Mechanization Research*, 39 (11): 64–68. Doi: 10.13427/j.cnki.njyi.2017.11.011

For more information

Wu Yin, Jinna Zhang, Lu Ma and Yanping Yu
Shenzhen Wissea Technology Co., Ltd.
yinwu@wissea.com; zhangjinna@wissea.com; malu@wissea.com; yuyanping@wissea.com

Ming Xiao
School of Automation, Guangdong University of Technology
xiaoming1968@qq.com



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39 Phra Atit Rd., Bangkok, Thailand 10200
www.fao.org/asiapacific

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