

Satellite Applications

White Paper UAVs for UK Agriculture

Creating an invisible precision
farming technology

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“Unmanned Aerial Vehicles (UAVs) for UK Agriculture: Creating an Invisible Precision Farming Technology”

White Paper

Mark Jarman, John Vesey, Paul Febvre

Foreword

This white paper from the Satellite Applications Catapult looks at how unmanned aerial vehicle (UAV) technologies can become an integral or ‘invisible’ precision farming technology exploitable by different users across the agricultural sector. UAV technology has not yet reached maturity, with many agricultural end-users failing to see any proven agronomic or economic benefits of the technology or data products.

The challenge, therefore, is to address the current status of how these systems are being exploited and to address this alongside other regulatory, operational and analytical developments. By doing so, UAVs can become an essential farming tool, both as imaging sources and as farming machines (for example as drone sprayers), in the same way that we associate farms with machines such as tractors, or enabling technologies such as real time kinematic (RTK) navigation.

By exploring the plans for the UK Government RPAS ‘Pathfinder’ projects and the current UAV landscape within agriculture, this white paper will consider how the identified enablers across four identified areas – Systems, Infrastructure and Platforms; Sensors, Data and Information Services; Products and Applications; Users and Benefits – can be exploited to ensure successful exploitation of UAVs within precision farming.

1. Introduction

The UK Government, through its UAV Pathfinder Programme, is working towards enabling UAVs to routinely travel ‘beyond visual line of sight’ (BVLOS) within controlled UK airspace by 2020. Its vision is: “to create an environment and enabling infrastructure (legal and regulatory framework and policy) in the UK that: drives growth in the private drone sector (users, manufacturers, services); facilitates public sector adoption (increasing efficiency and capability); and provides reassurance on societal concerns (safety, security, privacy, data protection”. The Government has identified a number of Pathfinder projects that will help achieve this through both the enabling of UAV airspace integration and understanding the impacts of this in applications areas such as parcel delivery, agriculture/geo-mapping and national infrastructure monitoring markets¹.

¹ <http://aerosociety.com/News/Insight-Blog/3698/RAeS-helps-set-the-drone-agenda>

A recent Markets and Markets report (2016)² projects the use of UAVs within agriculture to increase at a compound annual growth rate (CAGR) of 42.25% between 2015 and 2020, reaching a market value of around \$5.6 billion. From drone sprayers to advanced imaging drones, the potential opportunities for the UAV industry are endless. At the same time, the agricultural sector is under pressure to embrace new technologies and techniques in order to maximise agricultural output, driven by a global need to feed an increasing population from a shrinking area of cropable land. However, maximum exploitation of UAV technologies will only be realised if there is strong collaboration and engagement between the UAV and agricultural sectors, ensuring the following core sector and end-user requirements are met:

Agricultural sector	Agricultural user
<ul style="list-style-type: none"> Optimisation of crop yield and output. 	<ul style="list-style-type: none"> A simple and easy to use 'plug and play' technology providing data or usable as a machine.
<ul style="list-style-type: none"> An enhancement in product and produce quality. 	<ul style="list-style-type: none"> Actionable agronomic data and intelligence, with clear and proven value and benefit.
<ul style="list-style-type: none"> A reduction or better use in a sustainable way of the dwindling variety of available agrochemicals, such as fertilisers, herbicides and pesticides. 	<ul style="list-style-type: none"> Understanding of how this technology can be used alongside other precision farming techniques.

There is enormous potential for the UAV sector if it were to address these areas, given the opportunities that UAV technologies presents to users across the agricultural supply chain, either as a standalone solution or in combination with other data sources and precision farming techniques. The commercial potential for sales and services across the agricultural sector looks substantial, simply by assessing the cropable area of a country or region and multiplying against a prospective cost per hectare. However, to fully achieve its potential the UAV sector must not look at the sector in this way and 'push' the technology: instead, it should engage with end-users, from farmers to supermarkets and commodity traders to ensure their requirements are understood and that customers receive actionable 'intelligence' that enables better and more informed management decisions.

At present, mainstream acceptance of UAVs amongst the various users from across the agricultural sector is not being realised, with concerns raised about usability, the economic and agronomic justifications of the technology, and the data and services available.

"We are concerned that these technologies are more time-consuming and complicated than originally envisaged, which restricts our ability to collect and analyse sufficient data at frequency required to meet our objectives."

Dr David Nelson – Field Director, Branston Ltd

² <http://www.marketsandmarkets.com/market-reports/commercial-drones-market-195137996.html>

“The collection of data is time consuming and weather dependent. To maximise the technology requires the skills, knowledge and equipment to implement the task after the data has been collected and analysed. For example, it is great to have a geo-referenced weed map, but is entirely useless if there is no means to use the data.”

Andrew Williamson – Farmer and Nuffield Scholar

“The technology [hardware and software] works well; the barrier is in realising an economic benefit [increased yield and/or decreased costs] from the information produced by the UAV. Most potential adopters would like to see examples of how margins have improved before investing in these technologies or services.”

Dr Eric Ober – Senior Research Scientist and Crop Physiologist, NIAB

Given the focus on the technology, UAVs are often viewed as a ‘technology push’; delivering ‘picture agriculture’ rather than a tool meeting user needs and requirements. It is therefore critical for both the UAV and agricultural sectors to work together alongside the Government Pathfinders to prove the economic and agronomic benefits that UAVs can bring to precision farming, as opening up UK airspace alone will not increase uptake.



Figure 1 – The critical areas that need to be addressed to ensure that UAV technologies can be used appropriately and in combination with other data sources to deliver actionable intelligence with clear economic and agronomic justification.

Within our Sustainable Living Programme, the Catapult is exploring how we can help support the exploitation of UAV technologies for the benefit of the UK economy. Focusing on areas such as agriculture, we are collaborating and engaging across the breadth of the agricultural sector – and technology sectors associated with UAVs – to develop and exploit these technologies alongside other data sources, such as satellites, to ensure that timely and affordable state-of-the-crop intelligence can be delivered to farmers and growers. In this

white paper we will focus on how the enablers across the four areas identified in Figure 1 can be exploited to meet this aim.

2. Opening up UK Airspace – UK Government UAV Pathfinders

Through its UAV Pathfinder Programme, the UK Government is currently exploring how to create an environment and enabling infrastructure (legal and regulatory framework and policy) in the UK for UAV technologies by 2020 that will:

- drive growth in the private drone sector (users, manufacturers, services).
- facilitate public sector adoption (increasing efficiency and capability).
- provide reassurance on societal concerns (safety, security, privacy, data protection).

These Pathfinders are designed to take us from where we are in 2016, both in terms of technology and regulation, to a situation where industry can exploit the market across a range of sectors including agriculture. A number of Pathfinders have been established that focus on package delivery, agriculture/geo-mapping and utilities inspection, and these will address how opening up UK airspace will enable UAV exploitation.

2.1 Requirement for Airspace Change

Non-hobbyist users of UAV technologies for commercial revenue generation across the UK perceive that commercial exploitation is being stifled due to Civil Aviation Authority (CAA) operational regulations for commercial operation. These guidelines are based on platform size and weight, as indicated in Figure 2.

Small unmanned aircraft (weighing less than 20kg) are widely available for commercial and recreational use and are subject to safety rules, which are underpinned by UK law. Some specific additional steps that must be taken if a drone is being flown for 'aerial work' and anyone using a small drone needs to be aware of the regulations contained in the Air Navigation Order³.

Unlike small drones, UAVs with an operating mass of more than 20kg are subject to full UK Aviation regulation (as listed within the UK Air Navigation Order), although they may be exempted from certain requirements by the CAA. UAVs with a mass of more than 150kg are also subject to additional certification requirements as determined by the European Aviation Safety Agency (EASA). These larger drones are not currently permitted to fly in any non-segregated airspace in the UK without specific permission from the CAA, although they can be tested at a number of locations where airspace has been segregated to exclude other airspace users.

³ <https://publicapps.caa.co.uk/docs/33/CAP%20393%20Fourth%20edition%20Amendment%201%20April%202015.pdf>




UAV platform	Maximum category mass	Responsible regulatory body
	Small UAV (less than 20kg)	National aviation authority
	Up to 150kg	National aviation authority
	More than 150kg	European Safety Aviation Agency (EASA)

Figure 2 – UAV platform classes and responsible regulatory bodies

Small UAVs are the easiest for both service providers and agricultural users to exploit, given the accessibility of the technology and the flexibility of deployment. However, Figure 3 provides an example of the number of flights required to provide complete farm coverage of an averaged sized farm consisting of 18 fields totalling roughly 350 hectares given current CAA regulations. This presents considerable logistical challenges in terms of ensuring complete capture and the time taken to achieve it. It also has cost implications for the individual or business undertaking the capture.

For providers looking to provide service offerings including data capture, 18 deployments could require two, three or even four days of operation to complete, which would have to be costed into any product offering. A local user, such as a farmer or agronomist looking to operate their own platform, would face the same challenges which would have to be balanced against other farm processes requiring attention at the same time.

Relaxing regulation even by doubling current regulations to enable routine ‘extended visual line of sight’ (EVLOS) operation would make a significant difference by reducing flights required to roughly five (in this case) and therefore making commercial services or on-farm operation more viable, as shown in Figure 4. This could be through either a completely autonomous solution in which the UAV is making independent decisions within a controlled air traffic management system, or by using a solution with an on-board sensor through which an operator has the capability to view and make flight amendments during flight. Both of these options have the potential to improve efficiency (especially if swarming is considered). Autonomous solutions also have the potential to ensure full coverage and potentially more uniform data acquisition, simplifying data curation and thereby reducing cost and complexity.

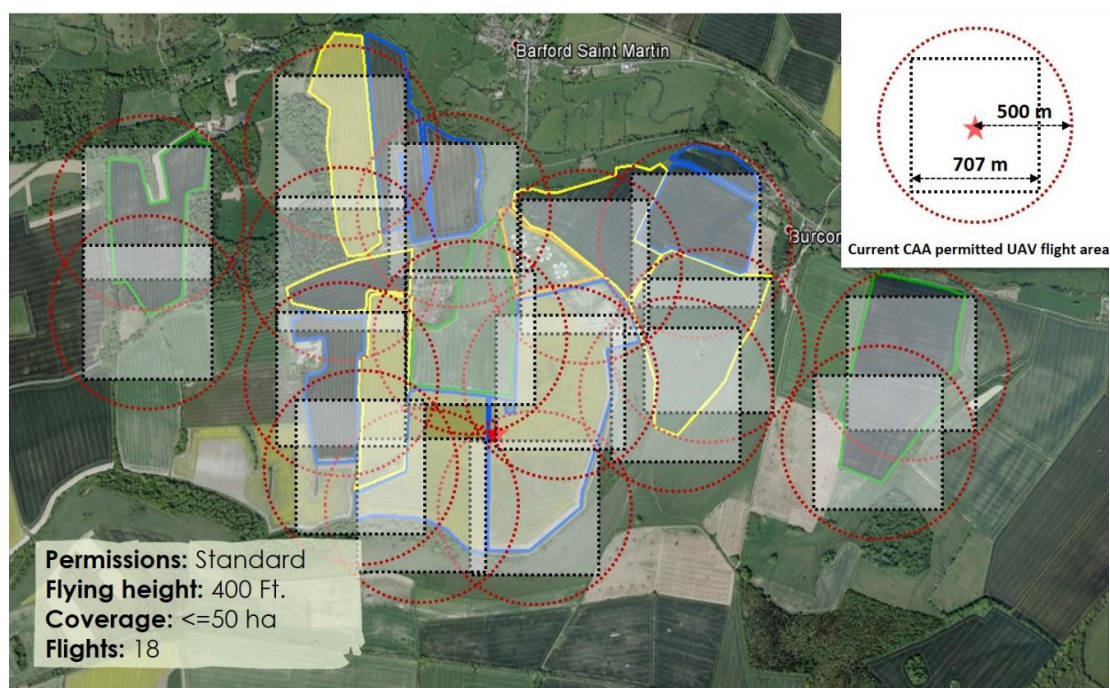


Figure 3 – Typical capture pattern based upon standard CAA regulation for 18 fields totalling 350 hectares

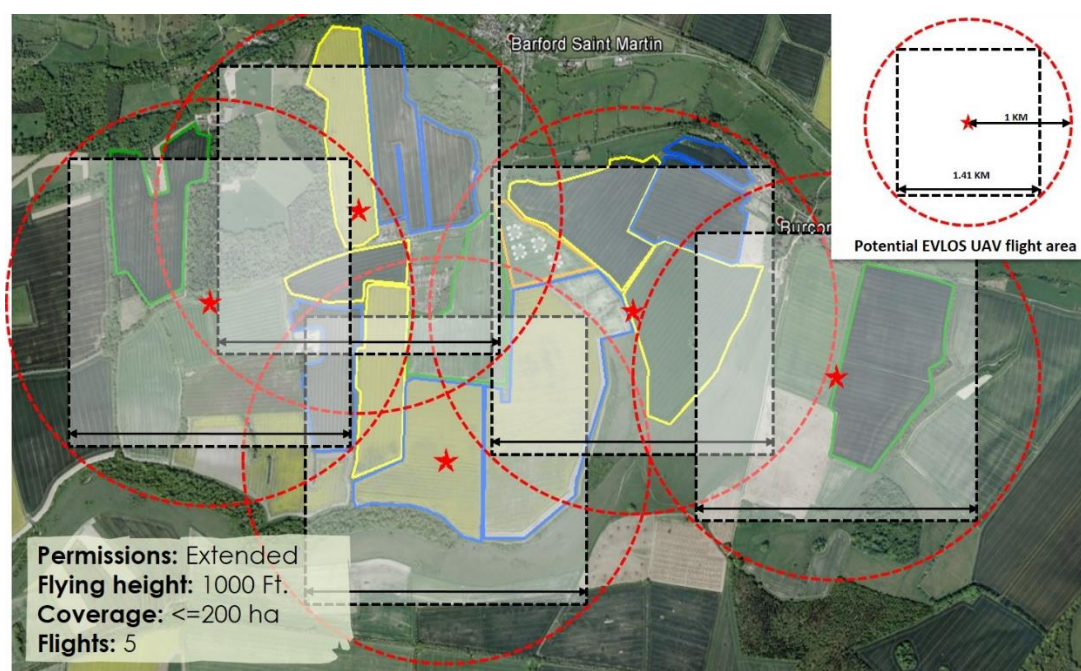


Figure 4 – How EVLOS regulation would reduce the number of required flights for a farm of 350 hectares from 18 flights to five.

Should the Pathfinder Programme deliver routine airspace access for UAVS by 2020, thus enabling larger platforms capable of operating BVLOS, opportunities for the commercial exploitation of UAV technologies across agriculture will likely grow. This alone will not guarantee exploitation however, and hence it is critical that the UAV and agricultural communities engage together to ensure the technology delivers economic and agronomic benefits to users.

3. Understanding the Current UK Landscape – UAVs & Agriculture

The opportunities to exploit UAV technologies for agricultural purposes has evolved substantially since the first flights of a UAV over UK farmland for precision farming measurement purposes were undertaken by Aberystwyth University and QinetiQ in 2008⁴. Since 2008, awareness and uptake, particularly by hobbyist users of the technology, has grown exponentially, principally following the release in 2013 of the first DJI Phantom UAV. The increased availability of these relatively cheap (around £1000) and simple-to-use UAVs with built in Global Positioning System (GPS) capabilities makes them perfect for users wanting to take aerial photographs of their crops. This ease of use plus their unique assessment opportunities has created substantial interest in both the UAV and agricultural sectors in how the technology can be exploited to generate commercial revenue.

Although small UAVs, such as the DJI Phantom, are increasingly being used by farmers to take aerial ‘pictures’ of their fields, the technology does not yet deliver sufficiently compelling services to be accepted as a ‘critical’ precision farming tool that delivers proven value, a viewpoint shared by both the UAV and agricultural communities.

“User expectations are generally on a level much higher than is realistic, especially if they have done a trawl of UAV advertising.”

Nigel King – Managing Director, Quest UAV

“The use of UAVs is not commercial at present; that have been used as a research tool but have yet to be proven as a useful piece of farm machinery.”

Keith Geary – Managing Director, G2Way

“I don’t think there has been enough work done to find the benefits of using them. Good data is being produced, but currently this is not deliverable to the farmer in a form that enables quick solutions as the algorithms are not specific enough yet.”

Lewis McKerrow – Head of Precision Technology, Agrovista

“Operating UAVs commercially as a daily tool on farms is not practical unless a specialised employee or contractor does it, offering the final product ready to use. This is due to the expertise needed to operate the platforms and process the data. As technology develops perhaps in they could become integrated into our business, but due to limitations such as these, we don’t see this happening in the near future.”

Sergio Moreno-Rojas – Remote Sensing Technologist, G’s Growers

Until the technology is proven to have clear economic and agronomic benefits, it is likely users will continue to make use of the smaller, cheaper platforms such as the DJI Phantom to take quick aerial photographs of their land. Going forward, it is important to develop the technology in ways that meets the requirements of the different end-users, whether that be through service provision or use of dedicated UAVs that have a targeted function, such as spraying.

⁴ <http://news.bbc.co.uk/1/hi/sci/tech/7547504.stm>

3.1 UAV Agricultural Service Provision

Since 2012, there has been substantial growth in the number of companies offering commercial services exploiting UAV technologies, driven by a growing interest from the agricultural sector about the attainable measurement opportunities. Increases in the availability of platforms and a growing user requirement for data and platforms at a justifiable price point has translated into changes in the dynamics of service provision between 2012 and 2016 (Figure 5). Although there are still substantial levels of research going on, the different service mechanisms that have developed can be defined as follows:

Service provision:	Companies are contracted to undertake data capture for the customer and supply requested data products.
Platform provision:	Companies typically selling airframes and sensor packages. Data product production may also be offered.
Data only:	Companies offer to process data acquired from third parties to produce data products, without operating or selling UAV technologies themselves.

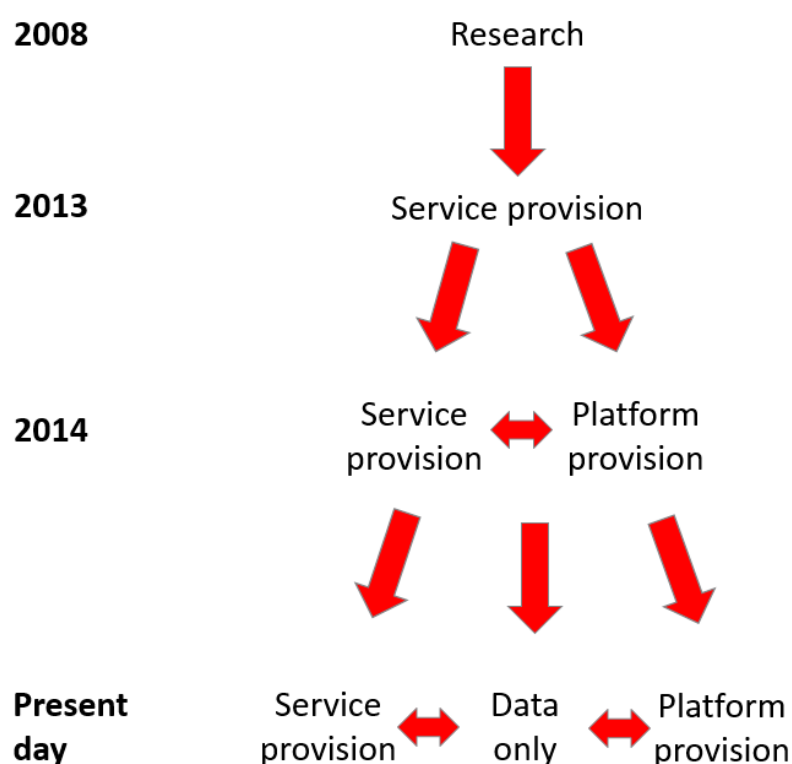


Figure 5 – The evolution of UAV services supplying data to the agricultural sector from 2008 to 2016

Commercial service offerings in the UK began to be offered in 2013 through companies such as URSULA Agriculture (no longer trading), with similar businesses in France (Airinov) and the USA (Precision Hawk) formed around the same time. These services began to gain traction due to a significant increase in UAV-related media coverage, technical advances in platforms, sensors and software, and interest from investors.

These early commercial offerings were typically based on a 'service-provision' model, whereby teams were deployed to a location with a UAV and data or imagery was collected and analysed to produce a range of measurements that had either been requested by a customer or, more likely, was produced to show what they might find 'useful', given that many customers lacked awareness of the possibilities. Services were priced on a per hectare basis with a minimum area order requirement, with a variety of data products available such as normalised difference vegetation index (NDVI) maps, crop cover and crop trials analysis.

This service-based model has become increasingly commercially unviable for customers, given the perceived high costs per hectare with little justifiable or proven economic or agronomic benefit. An economic downturn in the global agricultural market is leading to agricultural users being less likely to trial new UAV technologies or data products and increasingly demanding value and actionable decision making from the technology and data products on offer. This has made sustaining a commercially viable service based on the supply of UAV-derived data products difficult or impossible for many businesses. Leading UK businesses operating in this space that only offer these data products, such as URSULA Agriculture, have been forced to cease trading because they have been unable to generate sustainable commercial revenues. Conversely, UK providers who have focused on 'platform provision', such as Quest UAV, have been able to sustain their businesses and grow, driven by consumer demand for access to their own airframe.

Overseas businesses providing data products, such as Airinov and Precision Hawk, have been better able to embrace these agricultural market challenges and requirements. Both companies have received substantial investment in their businesses, and have created platforms and data packages that consumers could buy and exploit, enabling them to generate scalable offerings. Airinov has achieved commercial success to date by creating targeted systems, sensors and data products that are designed to meet customers' agronomic needs. It delivers actionable data products related to nitrogen application maps to over 5000 farmers around the world⁵ by leveraging networks of farmers to effectively become pilots for them. Precision Hawk not only exploits data captured by users of its platform but also allows users to use its algorithms to analyse data captured by third party platforms ('data only') through its online Algorithm Marketplace.

These UAV businesses have been able to scale and generate market traction, but many users from the agricultural sector still remain unconvinced about the perceived value and usability of the information being produced. Market penetration in the UK remains challenging, with new providers trying to generate market traction and established precision farming industry players, such as SOYL, experimenting with the technology but not yet offering large scale services.

3.2 UAVs as a Precision Farming Tool

The UK's geographic location ensures growers have to achieve maximum yields from a single growing season each year while managing changeable climatic conditions. Coupled with annual crop rotations, acceptance of new precision farming technologies and

⁵ <http://www.airinov.fr/en/company/about/#top>

techniques may take years, given the time required to properly prove and understand the agronomic and economic benefits attainable.

This is a plethora of different precision farming techniques and technologies available for farmers and growers. Figure 6 displays their maturity in relation to the Gartner 'Hype Cycle', a graphical representation of the lifecycle stages that a technology or application goes through from conception to maturity and widespread adoption. The term 'UAV' has been added to the curve, located on the slope towards the 'Peak of inflated expectations' based upon feedback from users across the agricultural sector.

When compared with other precision farming techniques, UAVs (when viewed as precision farming tools) are very much in their infancy. The task facing the UAV agricultural sector, therefore, is to ensure that the technology is moved along the curve to reach maturity and exploitation. However, the question has to be asked as to whether 'UAV' should be on the curve at all? Instead, would it be more appropriate to replace it with UAV specific machines (such as drone sprayers), techniques (such as UAV spot spraying) or data solutions (such as disease detection)?

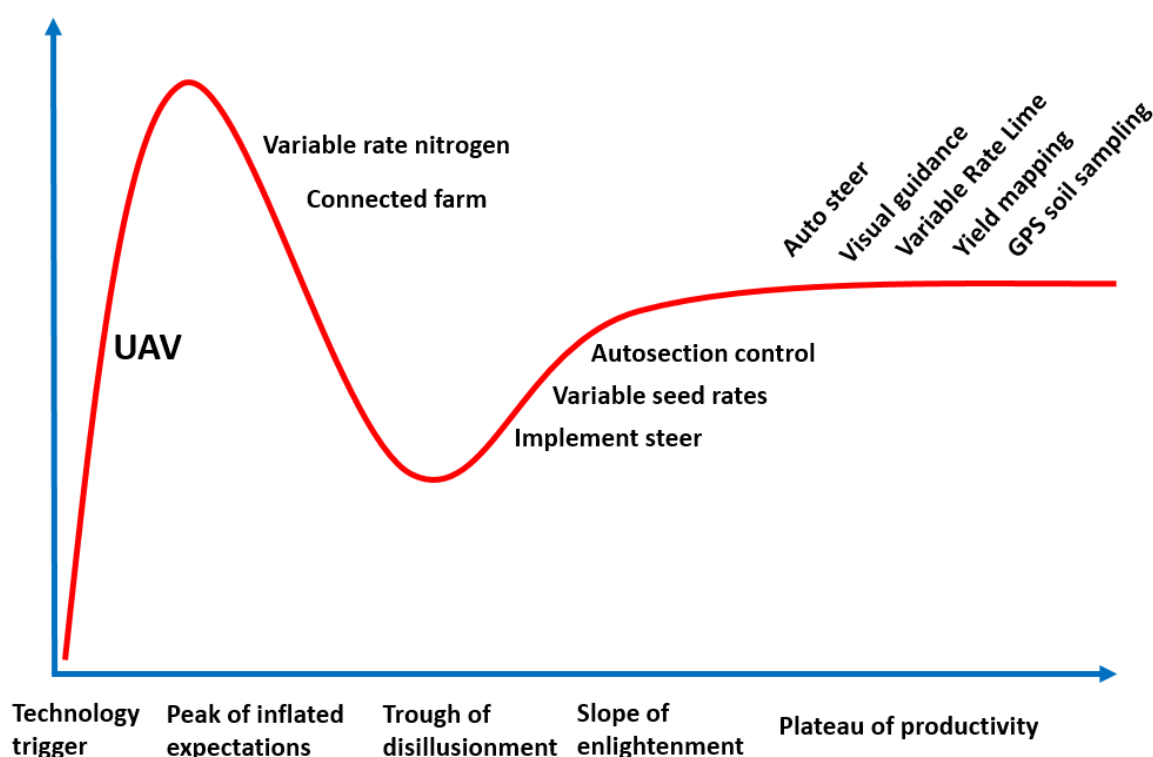


Figure 6 – A Gartner Hype Cycle representation of precision farming technologies and techniques

There is a need to better understand how UAV remote sensing technologies fit alongside other precision farming offerings that also exploit remote sensing techniques. For example, satellites or tractor-based remote sensing systems have been used routinely since the early 2000s as an input for 'variable rate' nitrogen application. Variable rate application refers to the application of different rates of fertilizer or manure to different parts of a field growing the same crop, based on a pre-determined prescription. The rate can be controlled manually by the equipment operator or automatically by a computer in communication with a GPS system.

Tractor-mounted sensing systems, such as the Yara N Sensor or Fritzmeier Isaria, provide growers with access to 'real-time' sensing opportunities. For example, as the tractor travels over the field, the crop is being 'sensed' for weeds or for nitrogen requirements and the information collected is used to vary the rates of chemical(s) released along the sprayboom located on the sprayer directly behind the tractor. Although tractor-based sensing is 'real time', to gain field or farm level data requires travel over the entirety of each field because the sensors only image the crops on either side of the tractor as it drives through the field. This can create soil compaction issues unless controlled traffic farming techniques are used to confine all machinery loads to the least possible area through the use of permanent traffic lanes. However, given that a tractor is in the field at critical points in a crop's lifecycle, or example for the application of various inputs, understanding how UAV technologies can support tractor-based sensing will be critical to ensuring the technology is used appropriately.

Satellite imaging technologies are routinely being exploited by UK precision farming providers such as SOYL and AgSpace. Typically using data from optical satellites, satellite data is used for variable rate nitrogen application or for field zoning whereby variations in the brightness of the soil prior to cultivation is used to split the field into zones depicting different soil types. However, the nature of optical satellites means that they cannot capture images through clouds and have specific, and sometimes long, revisit times, resulting in potentially long gaps between the acquisition of images of the same place. Therefore, required measurements relating to specific growth stages that are needed to help inform agrochemical application can be missed even when a satellite is overhead, reducing the value of the service offered.

To counter these issues, satellite technologies and data offerings are changing at a similar pace to the rapidly developing UAV sector:

- Satellite data is now commercially available at 30cm resolution from Digital Globe.
- Users can access free satellite data through the ESA Copernicus Sentinel programme, with image swaths of over 160km covering thousands of hectares in a single image.
- Synthetic aperture radar (SAR) data is becoming increasingly available. This active imaging source can penetrate through clouds and does not need daylight to collect images, opening new measurement opportunities related to crop structure and soil moisture.
- Planet Labs' planned constellation of hundreds of CubeSats is promising daily global coverage at 5m resolution.
- Optical satellite data archives dating back over 30 years, such as those from Landsat satellites, are available to agricultural users for assessment. This data has 30m or greater resolution but was acquired at better than monthly intervals, and hence offers the opportunity to drill down to analyse field performance and assess how management decisions have effected crop performance over time.

The selection of data sources from UAV, aircraft, tractor-based sensing or satellite technologies, or the ways in which they can be jointly exploited, needs to be understood to ensure the best possible services can be provided to the customer. Ultimately, customers should not have to consider the underlying technology or technologies, but instead have

access to services that provide high integrity intelligence and actionable information that has clear economic and agronomic justification.

Given the rapid growth of UAV technologies attributed to technological advancements and a growing interest from the agricultural sector, it is likely that the maturity of different facets associated with UAV technologies will potentially be reached in the short (1 to 3 years) to medium term (3 to 10 years). However, maturity in the UK will only be reached by appropriately considering the nature of the domestic agricultural sector and producing systems and data products that meet different user requirements.

3.3 Current Agricultural Industry Use

UAV technology and service providers aiming to exploit the agricultural sector and supply chain are faced with a complex system that is constantly operating in the context of various economic, social, climatic and environmental challenges. Figure 7 highlights the different scales of variability and field properties a grower must operate within and mitigate against to ensure crops achieve maximum yields each year.



Figure 7 – The differing factors and scales of variability a grower must operate and manage against each year to ensure production is optimised.

Long-term fundamental properties:	Climatic change, soil types, terrain, topography, levels of exposure
Mid-term manageable properties:	nutrient levels, soil structure and health, cropping cycles and field tillage techniques
In-season uncontrollable factors:	Climate, weather events, pest, disease and weed infestation

Without understanding how these factors affect the agricultural system, the supply chain, and user needs at critical management points within a crop's cycle, the UAV sector will struggle to supply actionable intelligence to users that is of both economic and agronomic value.

There are an increasing number of different users of UAV technologies and data products across the agricultural supply chain, each of which have different needs and requirements. Providers looking to sell UAV technologies, services and data products need to understand these requirements and their agronomic and economic importance and value.

Figure 8 provides an overview of the different users of UAV data products and services across the supply chain. Typically, those users in the circular boxes require data at the field or farm or regional scale, given the range of interventions such as agro-chemical application that the data is pitched towards. Researchers, crop scientists or breeders are often assessing trial networks consisting of tens, hundreds or even thousands of individual plots and so require data for each plot across the trial network. All users, however, require information at critical time points during a crop's growth cycle; an opportunity that can be made available by using UAV technologies, but only if the technology and data products deliver information of real value.

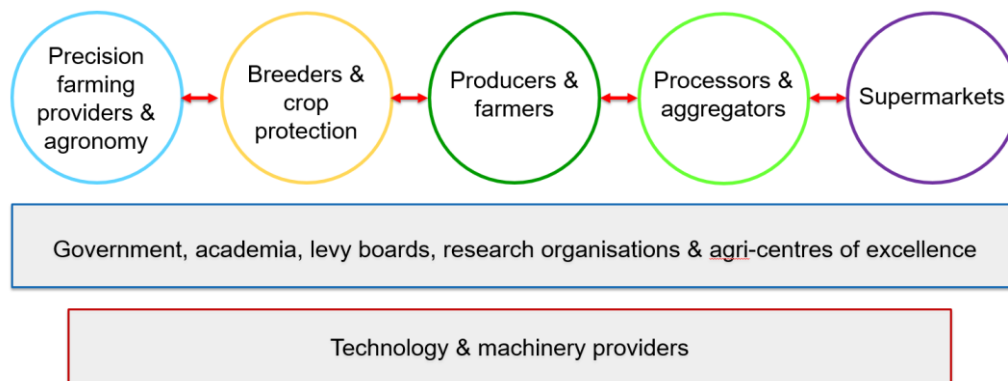


Figure 8 – Agricultural users currently exploiting UAV technologies

Those users from across the agricultural sector who wish to exploit UAV technologies are faced with choosing from an ever-growing number of UAV businesses offering agricultural data products and services that proclaim UAV technologies to be a critical and essential precision farming technology. This messaging is often very similar from one company to another, and may be ‘overselling’ the technology by suggesting that UAVs are a mature and proven precision farming tool that can deliver a range of data products.

Take, for example, this messaging: “...covering many hectares during just a single flight. Monitoring your land with precision farming technology enables you to achieve tasks that would have previously been expensive, time consuming, or not even possible....”

“Drones in agriculture can be used for monitoring or analysing:

- *Plant counts*
- *The impact of pesticides*
- *Land for insurance claims*
- *Soil moisture levels*
- *Canopy height and cover*
- *Erosion*
- *Crop colour and density*
- *Damage, weeds, disease, and pests”*

Users are increasingly becoming sceptical of such messaging, especially given that the measurements and products available are often generalised in form, with no clear definition or justification of their agronomic requirement, value or direct use. For example, each crop has numerous weeds, diseases and pests which affect the crop in different ways across the

crop's growth cycle. Therefore, without stating the specific weed, pest or disease and the subsequent product or measurement defined by a crop cycle point, it makes it very difficult for a user to purchase the data product or service with any confidence. Providers therefore need to ensure they understand the requirements and value of the products they are generating and how, through exploiting the technologies and available sensors, they can actually deliver them.

The types of measurement currently available to users from UAV service providers are driven by the platform and sensor technologies being exploited combined with the analytical capabilities of the company. Users of small platforms, such as the DJI Phantom, are able to extract simple aerial photography that can be used by the farmer or agronomist to locate areas of under-performing crops to target for further assessment. Larger platforms, such the DJI S1000 or SenseFly ebee, have greater payload carrying capabilities, enabling users to fly bigger cameras or sensors and in turn increasing the achievable measurements. Table 1 summarises the measurement opportunities available by exploring different sensing technologies available to UAV service providers and the key considerations that users must understand.



Figure 9 – Example black-grass mapping product produced by URSULA Agriculture. Areas with a high density of black-grass are shown in red

The most widely available data products are exploit RGB or colour infrared (CIR) cameras, given the low cost of procuring these sensors. These include measurements related to the performance of the crop, such as chlorophyll content, or maps of weed distribution as shown in Figure 9.

The measure of NDVI, which is a simple measure of crop greenness, is one of the most widely offered data products produced by exploiting CIR or multispectral sensors. Often scaled between 0 and 1, this vegetation index is a ratio of the red and near-infrared (NIR) spectral bands, and is used to highlight variations in crop productivity, with higher values representing more productive crops. However, without proper calibration of the imagery or sensor, these values are meaningless: in such cases, any users attempting to exploit this as an input dataset for nitrogen application are likely to make incorrect applications.

Table 1 – Different sensor technologies available for use on UAVs, their spectral characteristics and considerations for use.

Sensor	Typical spectral range	Product opportunities	Considerations
True colour (Standard consumer camera)	Red, green, blue	<ul style="list-style-type: none"> • Aerial photographs • Crop damage • Crop height 	<ul style="list-style-type: none"> • Analyses undertaken on the data likely to be of a manual nature • Crop height measures require use of a high accuracy baseline digital terrain model or use of ground control targets and ground survey during capture.
Colour infrared (Standard camera with near-infrared [NIR] blocking filter removed)	Red, green, NIR	<ul style="list-style-type: none"> • Simple vegetation indices, e.g. NDVI • Crop damage • Crop cover • Crop height 	<ul style="list-style-type: none"> • Calibration of the sensor or an appropriate calibration methodology to ensure consistent and comparable values within image products and vegetation indices. • Crop height measures require use of a high accuracy baseline digital terrain model or use of ground control targets and ground survey during capture.
Multispectral (A sensor rather than a camera typically consisting of 3,4 or 6 sensors, each targeting a defined spectral region)	Blue, red, green, NIR	<ul style="list-style-type: none"> • More complex vegetation indices (e.g. Canopy Content Chlorophyll Index) • Specific weed or disease maps (late detection) • Crop performance metrics (e.g. plant counts) 	<ul style="list-style-type: none"> • Calibration of the sensor or an appropriate calibration methodology to ensure consistent and comparable values within image products and vegetation indices. • Prone to changes in illumination from cloud cover variations. • Lower spatial resolution sensors.
Hyperspectral (Not widely used new sensing approach; images are collected containing a large number of discrete spectral bands or wavelengths in a line-scan imaging approach)	Red, green, NIR	<ul style="list-style-type: none"> • Complex vegetation indices requiring specific wavelengths. • Specific weed or disease maps (early detection) • Crop performance metrics such as vigour or chlorophyll content • Increased measurements opportunities around crop stresses. 	<ul style="list-style-type: none"> • Calibration of the sensor or an appropriate calibration methodology to ensure consistent and comparable values within image products and vegetation indices. • Sensors often high in costs and require increased remote sensing expertise to process and analyse. • Prone to changes in illumination from cloud cover variations. • Lower spatial resolution sensors due to size of instrument used. • Relatively unproven sensing technology from UAVs.
Thermal	Thermal infrared	<ul style="list-style-type: none"> • Crop stresses such as water or disease stress 	<ul style="list-style-type: none"> • Other variables, such as time of day or cloud cover, need to be considered when imaging the crop to assess temperature variations. • Relatively unproven sensing technology from UAVs.
LiDAR (Light detection and ranging)	Ultraviolet, visible, NIR	<ul style="list-style-type: none"> • Crop height • Biomass 	<ul style="list-style-type: none"> • Very expensive sensors.

Many operators of UAVs lack agronomic grounding and do not have a basic knowledge of remote sensing, which is needed to maximise the potential of data gathered from multispectral, hyperspectral or thermal sensors. Sensor packages such as Pix4D enable users to create simple data products such as NDVI, but data products considered critical by end-users, such as those related to weed or disease detection to target chemical application, often do not meet customer needs, are oversold or are not packaged in a way that makes them useable. Coupling agronomic knowledge with the correct technology and complementary datasets will be critical to creating data products that are directly exploitable, of critical agronomic importance and have a justifiable price point.

4. UAVs for Precision Farming – Steps to Invisibility

As outlined, the exploitation of UAV technologies, services and derived data products across the agricultural sector has yet to reach maturity. There are three main reasons for this:

- The cost of operating the remotely piloted airborne system platforms that are used to acquire the data is very high, owing to the intensity of human operation.
- The services derived from the acquired data do not (yet) have the tailored precision, integrity or quality to deliver adequately actionable information.
- The automated integration of the information into precision farming systems has not yet occurred, and therefore the process of translating the information into appropriate action requires manual intervention by a specialised analyst.

The technology and processes need to be improved in each of the three initial domains outlined in Section 1 (and illustrated below) before the benefits can be realised by users.

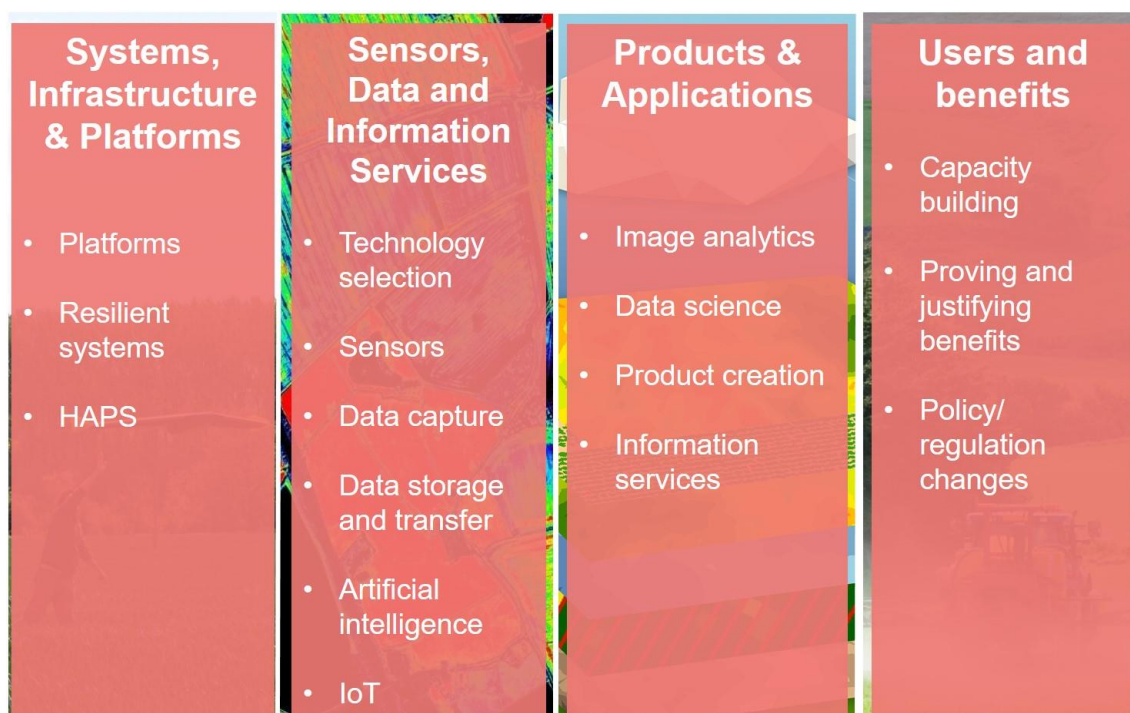


Figure 10 – The critical areas and associated enablers that need to be addressed to ensure that UAV technologies can be used appropriately and in combination with other data sources to deliver actionable

intelligence with clear economic and agronomic justification (HAPS – high altitude pseudo-satellite; IoT – internet of things)

Maturity is being stifled due to various blockers that are operational (for example airspace integration for BVLOS operation), technological (such as. data analytics and data integration) and commercial (for example business models). These need to be addressed through appropriate engagement between the UAV and agricultural sectors, with identified regulatory, technological and business enablers being developed to allow UAV-derived services to mature into useful precision farming tools and techniques. Only then will UAVs be able to provide transparent benefits and hence become ‘invisible’ tools within the farming community.

4.1 Systems, Infrastructure & Platforms

“Operationally, it is about providing equipment that is reliable, that comes with the right level of training, has been set up correctly for the end-user’s environment, and has excellent support.”

Nigel King – Managing Director, Quest UAV

UAV platform technologies, associated components and control mechanisms need to be developed in concert with changes in airspace regulation to ensure safe and cost-effective operation of UAV platforms. By also ensuring end-user requirements are understood, platforms can be developed for specific use cases to ensure maximum value is derivable.

4.1.1 Platforms

“UAVs cannot survey enough area per day with current legislation in a commercial context.”

Dr Toby Waine – Lecturer in Applied Remote Sensing, Cranfield University

“Legislation is also a key factor for their potential uses. The current uncertainty on this topic is likely to be preventing the agricultural sector from being willing to invest and learn about these technologies on a scale required for implementation in the marketplace.”

Dr Robert Freckleton – Director of Research and Innovation, University of Sheffield

Developments and advances in airframe technologies are continually improving the agricultural application opportunities available through the exploitation of UAV technologies. Questions remain, however, about how much these developments are actively driven by the needs of the user and their specific requirements. The majority of the UAV technologies on the market are equipped with a variety of cameras and sensors and presented as being applicable for use by all users to deliver critical measurements for any crop. Yet they must be easy to use by a non-specialist audience if a farmer or agri-business is going to invest in the technology.

With users having an ever increasing array of rotary, fixed wing and vertical take-off and landing (VTOL) UAV technologies to choose from, pitching the right technology at the right user based on their requirements is essential. At present there appears to be a fixation on rotary UAV airframes, given their ease of use and availability at appropriate price points. They are not, however, suited to wide area assessment and users should be advised instead to exploit fixed-wing or VTOL platforms. Nevertheless, uptake and availability of these

platforms is lagging behind rotary UAV technologies, given the substantially higher purchase costs and perceived added complexities of capture.

At present, it is often difficult for providers of the technology to demonstrate justifiable and clear economic and agronomic benefits when selling platforms. This is stifling uptake, given the capital investment costs required. Exploitation of the technology may, however, be better realised by producing platforms that target a specific user data need or machine requirement. Given the requirements to apply agrochemicals, a drone sprayer has a specific target audience and usage, and thus will likely be exploited correctly. In terms of 'imaging drones', to date providers like Airinov have found success by taking a focused approach, offering a platform and sensor combination that is easy to use and is specifically targeted at customers looking for variable rate nitrogen products.

4.1.2 Resilient Systems

As UAV platforms are developed for longer endurance flights, they must be secure and resilient to ensure they can operate safely and securely beyond visual line of sight. This will be critical to allowing changes to the regulations to accommodate platforms that are proven to be safe in operation, even in rural areas where the risk to people and infrastructure is relatively low. This will be of increased importance as UAVs are developed into 'farm machines' such as drone sprayers, which are likely to require autonomous operation 1m above the crop, bringing them into potential conflict with people, animals, other machinery and/or infrastructure.

The supporting systems will need to have very high integrity and availability. Flight plans for UAV operations will need to be created, cleared and deployed in operational systems, with means for safe and automated deviation from such plans in response to environmental factors. Monitoring the performance and behaviour will require new techniques and systems to be deployed.

Operational procedures will require resilient and ubiquitous communications, positioning and monitoring systems that can provide a support infrastructure for the safe operation of such platforms. Providing such a service support infrastructure cost effectively in the remote and rural areas in which agricultural activities take place will necessitate the use of satellite systems and services, as outlined below.

4.1.2.1 Communications

It is likely that the communications infrastructure will use a combination of direct line-of-sight, terrestrial cellular and satellite technologies. The wireless communications technologies currently used for direct line-of-sight operations will be essential for the initialisation phase to configure flight plans, check platform readiness and calibrate performance, and to support normal take-off and landing (comparable to airport and terminal manoeuvring procedures in air traffic management procedures).

In addition, line-of-sight communications will be exploited for communications between platforms to coordinate automated transient deviations from registered flight plans, in response to situation awareness. The terrestrial cellular and satellite technologies combine to provide cost-effective resilient communications infrastructure services for beyond-line-of-sight operation. While satellite communications technologies are currently typically only deployed on larger remotely piloted aircraft system (RPAS) platforms, the advancement of

satellite systems for airborne platforms is reaching the point where they can be cost effective to integrate into smaller platforms for operational use.

4.1.2.2 Positioning

Current positioning technologies based upon global navigation satellite systems (GNSS) are already used for precision farming, but the risks associated with deployment of higher speed autonomous UAV platforms are such that the technology needs to be able to have improved availability and resilience. Combining inertial systems with more resilient GNSS receiver technologies is becoming practical in smaller systems, driven by advances in the automotive sector for autonomous road vehicles, and these will need to be integrated into UAV platforms and certified for operation on such platforms.

4.1.2.3 Monitoring & Observation

Ensuring the safe operation of the deployed platforms and providing situation awareness to other airspace users will be critical. Since the platforms will be operating at low altitude, current monitoring systems based, for instance, on Automatic Dependent Surveillance – Broadcast (ADS-B) or Universal Access Transceiver (UAT) will be inadequate for monitoring beyond line-of-sight. A new system of observation, possibly exploiting the attributes of satellite or high altitude pseudo-satellite (HAPS) platforms will need to be designed and introduced to facilitate the safe interoperability of remote, autonomous UAV platforms with other airspace users.

4.1.3 High Altitude Pseudo-Satellites (HAPS)

High altitude pseudo-satellites (HAPS) or high altitude long endurance (HALE) platforms undertake long endurance flights at altitudes of around 20km and can be used for a number of technologies, such as persistent surveillance over a defined area. Other payloads have also been suggested for HAPS to support communication roles, for both military and civilian uses, including providing internet coverage to regions of poor or zero connectivity.

For agricultural imaging, HAPS is a highly complementary technology, sitting between the wide swath of satellites and the narrow capture of low altitude UAVs and aerial photography. The sensors on board could vary across the spectrum and provide a variety of data to support precision farming and other agricultural services. A number of organisations are testing and developing HAPS systems and it will be interesting to see how these use cases develop.

4.2 Sensors, Data & Information Services

“Our requirements are for a simple yet accurate technology which would help us quantify variation in performance of the crop and identify causes of poor growth. We are concerned that these technologies, however, are more time-consuming and complicated than originally envisaged.”

Dr David Nelson – Field Director, Branston Ltd

Understating how users collect, handle and manipulate data from different sensor technologies will be crucial to increasing uptake of the UAV technologies across the agricultural sector, both as a method of obtaining data and as a farming tool. The predominant use of UAVs at present is for remote sensing data collection purposes which

can generate gigabytes of data per flight. With expected changes in regulation brought about by the UK Pathfinders and opportunities for BVLOS operation, there is an increased requirement to become smarter in terms of data collection and manipulation. Data handling practices must be determined by user requirements for actionable intelligence provided potentially in 'real time', enabling users to exploit the technology in both proactive and reactive manners. Advances in these areas will open up possibilities and commercial exploitation for UAVs as farm machines, for example as spraying units.

4.2.1 Technology Selection

UAVs provide a means, alongside other sensing technologies such as satellite and tractor-based systems, of obtaining information and intelligence about the performance of and threats to the growth of a crop during its growth cycle. By understanding how UAV technologies can complement other imaging approaches within a stack of technologies (Figure 11), users can start to routinely monitor their crops throughout the growth cycle, ensuring they can intervene when required. This understanding, however, is lacking at present, with other imaging technologies viewed by the UAV community as a threat and as competing data sources, and with agricultural users not understanding what each technology is suitable for. For example, a farmer requiring a variable rate nitrogen service for 750 hectares of wheat, who is operating a sprayer with a 30m boom split into 10 sections, is better off using satellite-derived data products than exploiting UAV technologies. The cost of using UAV technologies will almost certainly be prohibitive given the area required for assessment and the scale and number of days required to capture this volume of data. In addition, the nature of current sprayer technologies does not allow the farmer to intervene at the resolution at which UAV data is captured.

Fundamentally, users from across the agricultural system should not have to consider where their information comes from. They should be able to access platform-independent information and actionable intelligence with confidence, as and when they require it. All of these technologies, if used appropriately and in combination, should create a form of persistent surveillance that enables the monitoring of crop development throughout its lifecycle. Users should be able to use this to proactively manage crops rather than being reactive, given that this information should enable them to intervene and address issues before they become critical. It is therefore vital that we understand how UAV technologies fit into this suite of available technologies and how they can all be used together to generate a routine crop monitoring tool.

4.2.2 Sensors

"There has been some progress with sensors for biophysical mapping (e.g. miniaturisation of LiDAR sensors), but sensor and software limitations have prohibited widespread use for now."

Dr Jerome O'Connell – Research Associate, University of Leeds

"Currently, the spatial resolution of multispectral systems is quite low, so only once an issue displays itself in large areas of crop can action be taken. Improved resolution would allow finer-grained analysis of crops, potentially beyond individual plant-level, to aid detection of problems earlier."

Dr Ian Hales – Research Associate, Bristol University

Given that UAV platforms are essentially a skyhook for putting a sensor in the air, selecting the correct sensor based upon the measurement requirements of the user is critical. Innovation in sensor technologies has been crucial to increasing the uptake of UAV technologies and potential product offerings for agricultural use. Table 1 provides a summary of the measurement opportunities and sensor considerations that must be made.

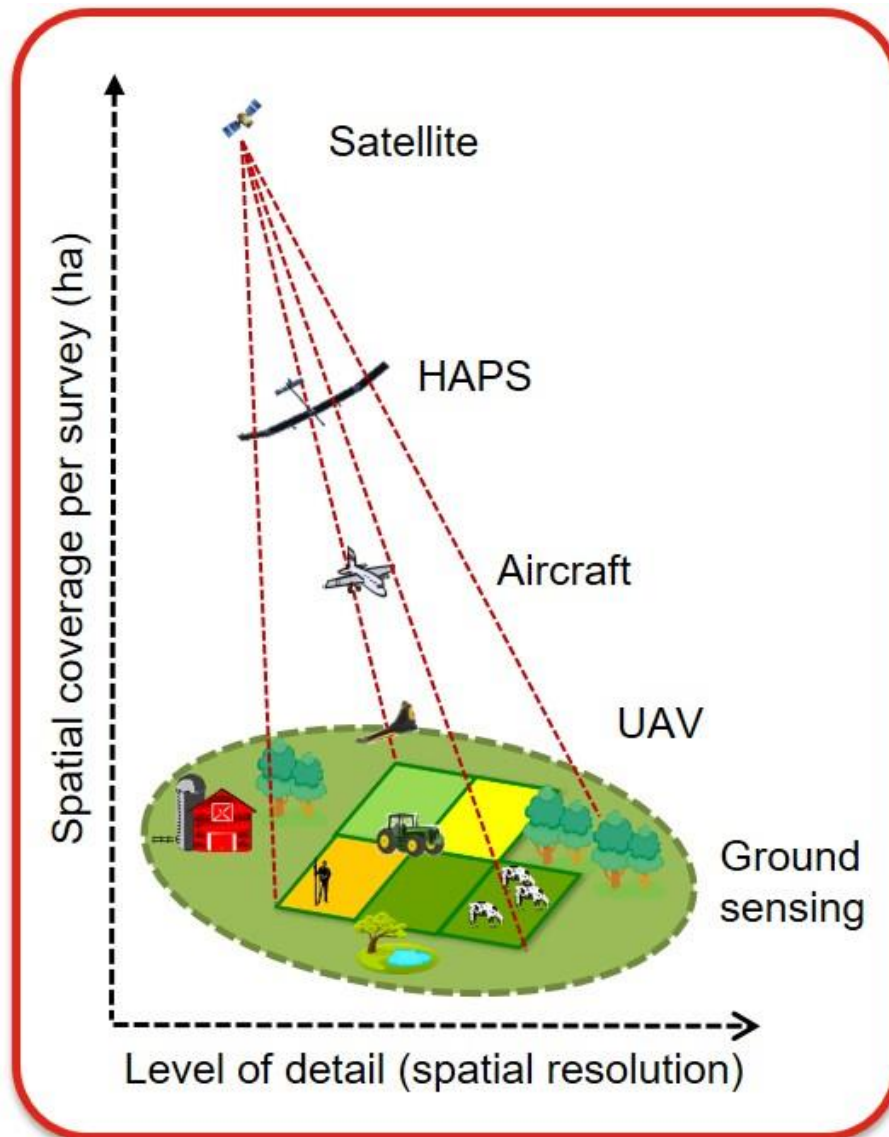


Figure 11 – The different imaging technologies available for exploitation by agricultural users to obtain crop intelligence and their associated coverage and level of detail

Relating the sensing requirements to user requirements still remains a challenge, particularly in relation to the detection of biophysical parameters and crop stresses such as water stress, disease and weeds. When attempting to detect a specific variable, both the spectral and spatial resolutions must be considered. Users operating UAVs are likely to be using a broadband colour infrared (CIR) camera which is unsuited for direct detection of disease, for example. Broadband CIR cameras could be used for highlighting broad field variation and for producing basic vegetation indices such as NDVI (if using appropriate calibration), but they

do not have the spectral capabilities required to distinguish subtle variations in the canopy such as the onset of a disease or an emergent weed.

Multispectral sensors offer greater spectral resolution than broadband cameras but their spatial resolution is much lower when operated at altitude. The size of the optics used to ensure they are small and light enough to be flown places constraints on the altitude at which platforms can operate to ensure the variable under consideration can be detected. This has direct and significant commercial implications, given the increases in operational capture time.

Exploitation and advancements in multispectral, hyperspectral, thermal or LiDAR imaging technologies will increase the measurement and application opportunities available to users. Developments in camera and sensor optics will be critical to growing commercial exploitation, particularly if airspace is opened for BVLOS operation. This must, however, be in combination with meeting the requirements of agricultural end-users.

As an example, weeds such as black-grass can be detected using current available multispectral sensors when the black-grass heads are above the crop in early summer (See Figure 12, left image). This, however, is too late for the farmer to apply herbicide to control the weed. What the farmer needs is sensors that can detect the weed earlier in its lifecycle (late autumn or early spring). Figure 12 (right image) highlights the scale of the challenge: the very thin green shoots are the emergent black-grass, while the thicker green shoots are the wheat plants. Only by selecting a sensing technology that has both the appropriate spectral and spatial resolutions will a user be able accurately locate the emergent black-grass. Whether a UAV is the right technology for this particular measurement also needs to be considered.



Figure 12 – Black-grass heads above the crop in early summer (left) and after emergence in late autumn (right)

4.2.3 Data Capture

Regulatory changes related to the opening of UK airspace and the enabling of BVLOS operation open up the prospect of wider area assessment opportunities but present challenges for capture planning and data integrity. Current operational guidelines are restrictive in terms of flight time and total capture area per flight, but they are short enough to allow acquired data to be removed from the airframe at site, processed either locally or online in the cloud, and returned to the customer within 24–48 hours. Longer endurance flights will scale up the task of obtaining the acquired data fast enough to allow data products to be produced and delivered to users in a timeframe that ensures the value of data products is not diminished. Servicing this change will require application of opportunities presented by

live streaming data through 4G or 5G networks, on-board data processing and/or advances in imaging and data analytics to only sense the variable under consideration.

The mechanisms of data capture also need to be carefully understood in order to exploit BVLOS operation. The nature of UAV capture for imaging purposes requires numerous flight legs over an area to ensure each image frame has an overlap of 60% or greater in all adjacent frames as this is critical to image orthorectification processes. Shorter flights are restrictive, but they do maintain the integrity of the data as the time between frames on adjacent flight legs is short enough for spectral measurements to be comparable. BVLOS operation increases the opportunities for longer flight legs, which in turn increases the time between adjacent flight legs: this could result in measurements related to the crop canopy between image frames not being comparable and in apparent variations being highlighted due to changes such as differences in the sugar levels present within the leaves, when in reality there are no variations. Flying higher may lessen the impact of this as image footprints would be larger, but this would lead to lower resolution data. Hence a trade-off will have to be made between image resolution and flight capture design that is driven by measurement requirements.

There are enormous opportunities associated with how we capture data and what data is acquired. With advancements in sensors and analytics, questions have to be asked related to the need to acquire imagery at all. Direct sensing of a specific weed, disease or biophysical variable as the UAV is flying over the crop in 'real time' will open up huge opportunities, particularly in relation to UAV machine developments such as drone sprayers.

4.2.4 Data Storage & Transfer

With advances in sensor technologies and larger platforms capable of carrying bigger and more sensors, data storage both on the platform and on the ground presents both challenges and opportunities. A standard flight based upon current CAA operational guidelines typically creates a few gigabytes of 'raw' image data which is stored locally on the airframe. Once downloaded, and if processed locally using suitable hardware, this volume of data can be turned into a data product quickly and exploited by the farmer within 24 to 48 hours. Moving this volume of data (and data from other flights) up into the cloud for online processing presents a challenge, particularly for users in areas where connectivity is poor. This issue will only increase with as flights get longer and data volumes increase.

Current practices necessitate that once acquired, this 'raw' imagery is processed into calibrated mosaics. These 'raw' image tiles are therefore no longer required, which significantly reduces total data volumes that must be moved prior to analysis and product creation. Maximising opportunities to create these image mosaics locally is therefore essential to optimise data transfer to the cloud, particularly for users not wishing to process the data themselves in areas with poor connectivity.

Should BVLOS operation and complete autonomy become enabled, users will be operating UAVs further and for longer. Significant questions therefore need answering about how users can handle data more efficiently to maximise the potential value derived from the data, critical to which is ensuring users can intervene at required management points.

These issues related to data storage present opportunities for developments in both processing on the airframe to generate image mosaics during flight, and in seamless downlinks of data during each flight to enable image mosaic creation in real time at a base

station. With advancements in complete autonomy enabling UAVs to operate independently and developments in UAV farm machines such as drone sprayers, the requirement for real-time data capture, processing and analysis to enable spraying will potentially negate some of the data storage issues that traditional remote sensing surveys create.

4.2.5 Artificial Intelligence

“I would like to see more automation regarding data collection on a more frequent basis.”

Andrew Williamson – Farmer and Nuffield Scholar

“We should not involve farmers in the technicality of data collection, data processing and analysis. What the farmers need is a simple process to ask for ‘knowledge’. They want to make a decision, then in an automated way for the UAV to collect the data, process it, analyse it and send it back to the farmer.”

Dr Shamal Mohammed – Precision Farming Specialist, GeoInfo Fusion Ltd

UAVs that operate with complete autonomy and that can make decisions for themselves are likely to revolutionise the way that data is collected. Should airspace open to allow BVLOS operation, the requirement for platforms to make decisions for themselves, and ultimately for full autonomy, will increase, particularly to ensure data and information is captured and delivered efficiently. End-users increasingly want to have access to their own platform, so the economic value of the technology will increase if the need for them to operate the platform can be minimised while still ensuring it is delivering agronomic benefits. UAVs that can be deployed automatically based upon an issue being highlighted by external intelligence (for example from a satellite assessment highlighting an unexpected change) will enable the user to become proactive, rather than reactive.

Increases in UAV autonomy and intelligence will also increase the measurement opportunities available to agricultural end-users. For example, a UAV flying over a vegetable crop prior to harvest could measure maturity characteristics and selectively mark crops ready for harvest, dictating to field teams where they need to go. With labour costs accounting for a large percentage of the cost of growing fresh produce, this could proffer high efficiencies in labour usage.

This level of autonomy and intelligence will be critical in enabling UAV ‘farm machines’ to become exploitable. Given the nature of a UAV which is operating above the crop and therefore not impacting upon the soil, drone sprayers could be routinely operating over a farm, spraying areas that require an input, rather than waiting for an agronomist or farmer to assess a field and make a decision.

Complete autonomy and increases in intelligence opens up the possibilities of drones working individually or together as part of a ‘swarm’. This swarm approach, coupled with a reduction in the cost of platforms and sensors, and the potential opening of airspace, offers the potential for users to deploy and exploit a number of UAV airframes in combination or operating independently with different functionality. As a result, users could obtain information in ‘real time’ without having to wait for a single drone to do a survey in potentially changeable climatic conditions.

4.2.6 Drones & the Internet of Things (IoT)

UAV technologies are well suited for deployment on farms as part of an ‘internet of things’ (IoT) network of sensors. The flexible nature of the technology and its ability to be ‘localised’ makes it the perfect tool to work alongside infield sensors, enabling intervention when issues or threats to crop growth are detected. This will not just benefit farmers but also other users from across the agricultural sector, such as large processors. A user located in an office could deploy a drone from miles away on the basis of real-time intelligence.

Increases in levels of connectivity will also be critical to ensuring UAVs can operate within an IoT setup alongside ground-based sensors. Opportunities for routine farm monitoring utilising different technologies, sensors and data sources should enable UAVs to operate and intervene with complete autonomy, removing the need for a user to make a decision. In-field sensors or information derived from satellite data could be used to detect unexpected anomalies in crop growth indicative of a crop under stress. This could lead to the automatic deployment of a UAV to investigate, take a sample or apply direct intervention.

The exploitation of UAV technologies as part of this sort of system will only be achievable, however, if rural areas can increase their level of connectivity, particularly in relation to mobile and internet connectivity.

4.3 Products & Applications

“There are so many potential uses that people can be daunted and overwhelmed by what to do with them. So by presenting a reduced number of things that they can do, but emphasising the economic impact that they can generate, then there is more chance that they can be used as single issue solvers to begin with and then expand their applications.”

Dr Robert Freckleton – Director of Research and Innovation, University of Sheffield

As outlined in Section 3, users from across the agricultural sector can exploit the various emerging applications and measurements offered by UAV technologies in an increasing number of ways. However, understanding user requirements and delivering data products and applications that actually require the use of UAV technologies will be critical to ensuring users exploit UAV technologies appropriately. When used as a remote sensing data source, UAV technologies are simply another mechanism for obtaining data alongside sensors on satellites, aircraft, tractors and the ground. It is important, therefore, that UAV service providers use UAV technologies to produce appropriate applications and data products, as this will ensure maximum value to both providers and users, while also reassuring users that they are not being oversold a technology unsuited to their needs.

4.3.1 Image Analytics

Coupling advances in sensor technologies and data analytics with the creation of actionable agronomic measurements will be critical to growing exploitation of UAV systems, services and products. Data used to target the application of various agrochemicals requires users to be delivered information at critical time points during a crop’s development or when a crop begins to show signs of stress, which may be indicative of disease or deficiency. This requires critical information to be supplied as fast as possible, often in near ‘real time’, to enable intervention.

With changes in regulation permitting longer endurance flights and advances in UAVs as farm machines, requirements related to real-time analytics are becoming more important. For example, fully autonomous drone sprayers that are capable of active sensing and immediate application of agro-chemicals as they fly over the crop would offer a technology comparable with tractor-based sensing and application offerings currently available from Yara and Fritzmeier. Tractor-mounted sensors are very useful for fertiliser application at a field scale, but they require the machine to travel through the crop, which farmer prefer not do daily given time pressures and issues relating to soil compaction. A drone sprayer that can offer real-time sensing and analysis capabilities and is deployable throughout the season will increase opportunities to control weeds, pests or disease by enabling targeted application at critical intervention points.

4.3.2 Data Science

UAV technologies provide value when a specific information or action is required, such as the application of chemicals or the creation of a map of weed distribution. However, if derived data products are exploited within a 'data science' decision-making approach (Figure 13), the value of the data and information can become much higher and of greater relevance to the user.

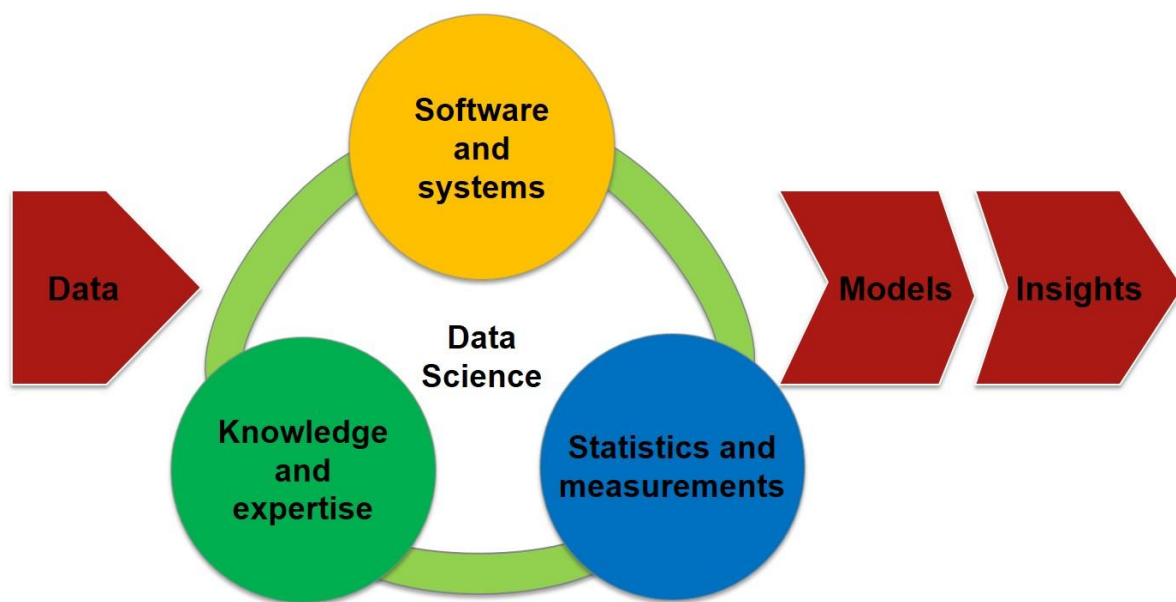


Figure 13 – An example data science approach whereby UAV data is used as an input alongside other data sources, knowledge and software to create models and, ultimately, critical insight and intelligence

Data or information products derived from UAVs should be inputs alongside data from other sources, such as satellites, and both live and historical farm data (for example soil or yield data) and climatic information (Figure 14). Crop models can be generated by using the correct software and systems, coupling agronomic and remote sensing knowledge and expertise, and incorporating critical measures and statistics. These models are essential for both monitoring and predicting what will happen to the crop during its growth cycle, allowing the user to assess how the crop is actually performing against expected growth. This insight is critical to enabling the user to make better decisions which are key to optimising yield at the end of the season.

Understanding how UAV-derived data can interact with other data sources within this approach is required, particularly if routine farm monitoring through persistent surveillance type approaches become enabled.

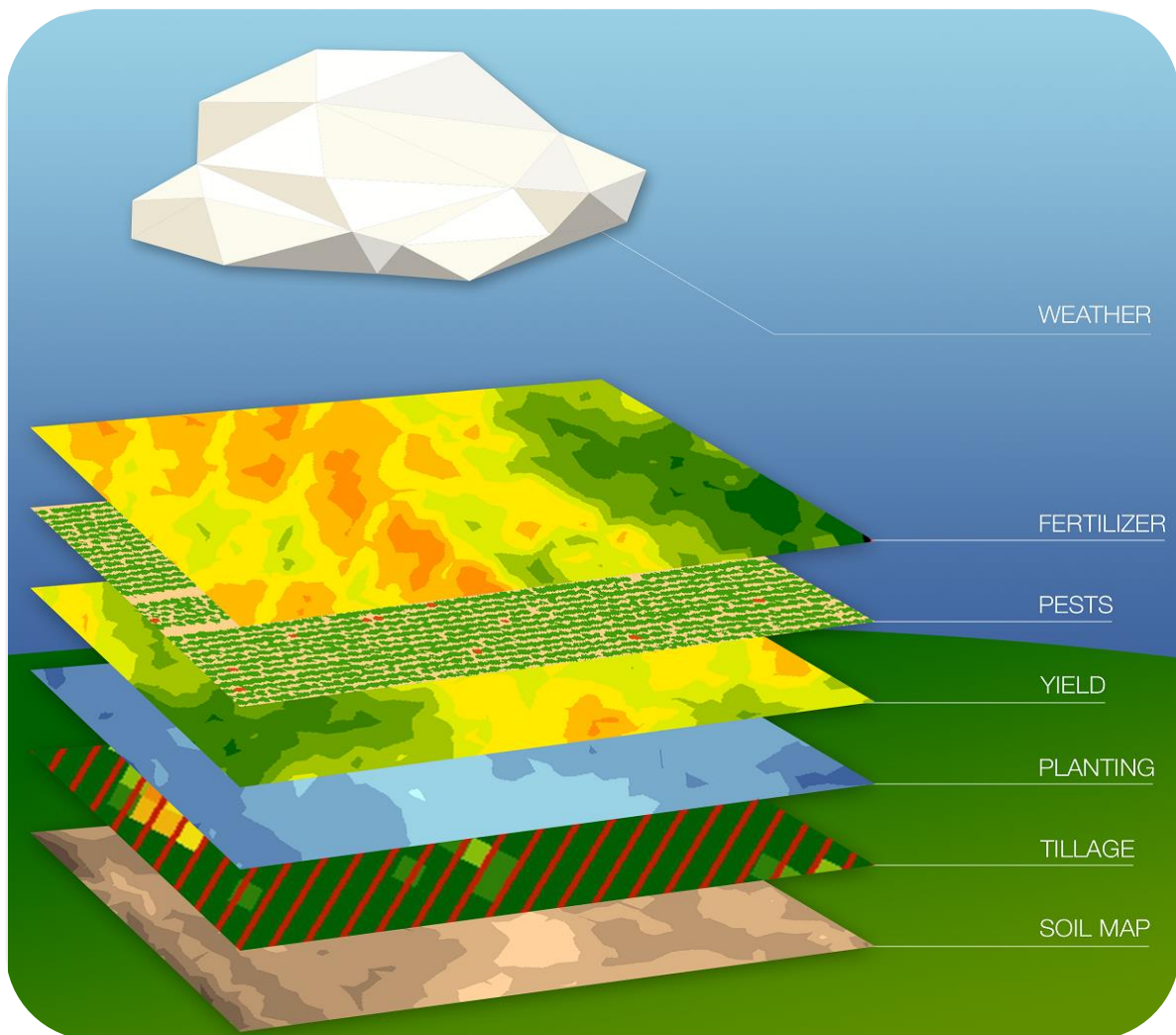


Figure 14 – Example data held by farmers, both historical (e.g. soil maps and yield data) and live dynamic information such as weather

4.3.3 Product Creation

The value of supplied products is maximised when the user is actively informed about a problem and can intervene immediately, rather than having to spot an issue themselves and find it is either too late to intervene, or having to wait for a third party service provider to provide them with data. This opens up significant opportunities around persistent surveillance for the routine monitoring of crops across the growing season by exploiting multiple data sources and sensors. Changes in crop development from a predicted ‘norm’ can be detected much quicker by making use of advances in computer vision or machine learning analytics within a ‘data science’ approach, rather than through field assessment, enabling the user to become pro-active rather than reactive. If data products can be supplied that are directly exploitable, such as an application map for fertilisers, then the user has actionable intelligence they can directly use without the need to consider data processing and analysis.

4.3.4 Information Services

“At the farmer level, it is having the skills, knowledge and equipment to implement the task after the data has been collected and analysed. For example, it is great to have a geo-referenced weed map, but is entirely useless if there are no means to use the data.”

Andrew Williamson – Farmer and Nuffield Scholar

At critical points in the growing season, agricultural users ideally require data and information that can be exploited directly on a farm machine such as a sprayer with little requirement to process or analyse it themselves. Standard data products such as NDVI provide farmers with intelligence, but they are not directly ‘ingestible’ by a sprayer and require interpretation alongside other datasets to create application maps.

These data products are most likely to be exploited by importing them into a farm management software package such as Gatekeeper or Muddy Boots, which are widely used in UK arable farms. These software packages, which are either cloud or desktop based, contain all of the farmer’s information and records about each field, and are used for monitoring and to make critical management decisions. However, the systems are often not optimised to handle the volumes of data produced by UAV surveys and so in order for data products to be exploited by users, they must be produced in formats ingestible by these systems. UAV and software companies need to work together to make exploitation of UAV data and data products more routine, but to date this has not been a priority due to a lack of demand from the end-user customer base.

There are a number of barriers preventing the exploitation of data products directly on farm machinery. UAV service and data providers looking to provide recommendations for the application of agrochemicals require agronomic grounding and the proper certification, such as the BASIS Fertiliser Advisers Certification and Training Scheme (FACTS). There are also issues in the sector with compatibility between implements (such as sprayers or drills) and tractors. Many of these implements are often directly only useable with other tractors of the same brand due to the use of proprietary file formats. To overcome this, farmers are forced into using different ISOBUS boxes in their tractors to standardise the communication between the tractor and implements. Unless the agricultural industry brings in a standard operational language that all implements and machines must adhere to, service providers will either have to exploit farm management packages or work closely with implement manufacturers to ensure their products and data products are compatible.

4.4 Understanding Users, Delivering Benefits

Without presenting a clear agronomic and economic case for UAV technologies and data products, market opportunities available across the agricultural sector will not be realised. Understanding and meeting the needs and requirements of the different users from across the agricultural sector is the critical enabler to ensuring the technology is exploited appropriately. Long-term collaboration between both the UAV and agricultural sectors is therefore required to create systems and data products that are proven to have agronomic and economic justification. Without that UAVs will be seen as a simply ‘technology push’ looking at agriculture as a market opportunity.

4.4.1 Capacity building and training

“Operating UAVs commercially as a daily tool on the farms is not practical unless a specialized employee or contractor does it, offering the final product ready to use. This is due to the expertise needed to operate the platforms and process the data.”

Sergio Moreno-Rojas – Remote Sensing Technologist, G’s Growers

At present, providers of systems, services and data products are viewed by many users across the agricultural sector to be ‘pushing the technology’ rather than producing something that is ‘fit-for-purpose’ and that meets specific user requirements. This partly however is due to the user not having the awareness of what the technology can do, how it can be used, or what data products can be supplied through using it. Therefore, increasing user awareness of the technology and the opportunities available will be critical to increasing uptake. This has to be done though with clear agronomic grounding, critical to building confidence in users that systems, services and products being provided have clear agronomic and economic benefits.

Engagement between the sector, end users and industry certification bodies such as BASIS will ensure that this gap in understanding is bridged guaranteeing that systems and products can be sold in the correct way and purchased with confidence by end users.

4.4.2 Proving and justifying agronomic and economic benefits

“The operational, agronomic and economic benefits need addressing in combination. UAVs must be seen as part of the solution not the whole, working alongside other data gathering/ sensor systems in a combined approach. We need valuable data that is consistent, repeatable, and with integrity.”

Chris HarryThomas – Farmer and Precision Farming Specialist

Without clear agronomic or economic justification of the available systems, services or data products, it remains difficult for agricultural users to engage with UAV technologies. The sale of these to users remains hugely challenging or even impossible for many service or technology providers at present. Coupled with a technology that is in its infancy when compared to other precision farming technologies, providers often do not have the agronomic grounding to understand the business proposition to different users from across the agricultural supply chain. Creating systems and data products of value will only be achieved through collaboration and long-term research over a number of growing seasons and rotations. This will ensure the economic and agronomic value proposition is better understood and the subsequent farm management decisions this enables.

Collaborative engagement aimed at proving direct benefits will be required for each crop and associated customer from across the supply chain given the range different associated issues and challenges. Confidence and awareness building will likely also be required to ensure user needs are properly understood and the correct information and intelligence delivered. For example, there are numerous weeds, diseases and pests which effect the crop in different ways and at different points across its growth cycle. Systems and products produced related to these areas will therefore also have a different value and enable different management decisions for each user. A farmer or agronomist will want to know the location of specific weeds or disease across a farm to enable effective applications of

herbicide or fungicide, while an agro-chemical provider would like knowledge of weed or disease locations at a regional or national scale to better target supply of their herbicide in order to increase sales.

With farmers looking to maximise yields year-on-year, a map locating specific weeds at a critical point in a crop's growth cycle, for example for use in post-emergence application, enables a farmer to better intervene. This has clear agronomic, economic and environmental benefits as the farmer can target areas that need it rather than applying standard blanket field application, thus reducing agro-chemical usage. A mid-season assessment when the weeds have established themselves has value for management decisions for the following year, but less immediate value because at this stage the farmer cannot apply herbicide to control the weed and must instead destroy both the weed and crop.

A drone sprayer equipped with advanced imaging and analytical capabilities operating completely autonomously could increase this value even further, for a number of reasons. Firstly, without the need to travel over the crop in a heavy machine, soil compaction issues are reduced. Secondly, if the sprayer drone can operate autonomously and BVLOS, the crop can be assessed routinely over its lifecycle and interventions made accordingly. Thirdly, with on-board imaging and analytical capabilities, weeds or disease can be detected directly, enabling real-time interventions to be made.

Uptake of products or systems such as these will only be achieved by ensuring users have high confidence levels in the systems and products that are on offer, and can see clear, proven agronomic and economic benefits. Users ultimately want intelligence that can be directly exploited, either through ingestion into a machine such as sprayer or into a farm management software package that is accessible anywhere. Meeting these requirements will be critical.

4.4.3 Policy/Regulation Changes

Technological advancements leading to new farming tools such as drone sprayers will require changes in policy and regulations. Given the direct actions that these on-farm machines will enable, such as the distribution of chemicals into the air, users from the UAV community will be required to work closely with regulatory bodies to prove the viability and safety of such systems. In addition, because machines such as drone sprayers will probably operate autonomously, it will be critical to prove that such a machine can operate safely and to mitigate against third party interference in order to ensure uptake.

5. Summary

In future, UAV technology will become an 'invisible' precision farming tool exploitable by different users across the agricultural supply chain. From simple UAVs that capture aerial photographs to drone-based farm machines such as sprayers, different users will be able to routinely exploit the technology without having to think about it. At present, however, the technology cannot be viewed as having reached this level of 'maturity', given the lack of proven and justifiable agronomic and economic benefits, particularly in a UK context. This white paper has therefore highlighted many of the enablers required to ensure UAV

technologies can be exploited correctly by agricultural end-users and meet their requirements.

5.1 Government Pathfinders

Current CAA regulations limiting UAV operation to within line of sight is preventing both the UAV and agricultural sectors from commercially exploiting UAV technologies for agricultural purposes. To help overcome this operational constraint, the UK Government, supported by bodies such as the Catapult, is actively exploring, through various Pathfinder projects, how to create and implement the best environment in the UK for UAV technologies and to enable the development of an appropriate infrastructure (legal and regulatory framework and policy) by 2020 that will open up airspace for BVLOS operation and complete autonomy. Simply enabling a UAV to fly for longer and cover more area will not, on its own, ensure the technology is exploitable by agricultural end-users. It is therefore essential that the Agricultural Pathfinder Project and the Catapult engage with the agricultural and UAV sectors to ensure that this work is complemented and the technology is developed and exploited correctly, driven by specific agronomic requirements.

5.2 Next Generation Drones

Driven by the needs of the agricultural end-user, new drones with complete autonomy will emerge, either as imaging platforms similar to their use today, or as drone machines with specific applications (for example a drone sprayer). These developments will be shaped by addressing the enablers highlighted in Section 4.

Advancements in airframes, components (such as batteries) and sensor developments, coupled with complete autonomy and artificial intelligence, will make UAV technologies highly exploitable, particularly if airspace is opened up for BVLOS operation. Autonomy opens up the possibilities for 'proactive' farming. Next generation UAVs equipped with sensors containing better optics and capable of 'real-time' analysis will change the way data is collected and the measurement opportunities attainable. Current methods for data capture create huge volumes of data that must be transferred to a destination for processing and analysis. Questions have to be asked as to why we must collect all of this data, and whether there are better ways to image, extract information and generate intelligence.

Routine monitoring of crops will become achievable by exploiting other information from satellites and weather data, and by targeting areas for assessment, and then moving the processing and analysis capability onto the UAV, enabling the user to become proactive, rather than reactive. Coupling these developments with evolving 'farm machine' UAV platforms such as sprayers will provide users with tools that can operate, make decisions and intervene in 'real time', which is critical to optimising disease control.

5.3 Delivering Actionable & Proven Agronomic Intelligence

The agricultural sector is under huge pressure to embrace new technologies and techniques to maximise agricultural output. This pressure is driven by a global need to feed an increasing population from a diminishing area of cropable land. To help alleviate this pressure at a farm level, farmers are constantly fighting to ensure they:

- Optimise crop yield and output.
- Enhance product and produce quality.

- Reduce use of – or use in a better, more sustainable way – the dwindling variety of available agrochemicals such as fertilisers, herbicides and pesticides.

The role of geospatial information in agricultural management will therefore be critical to supporting farmers in overcoming these production and environmental challenges. With appropriate use, regulatory change (legal and regulatory framework and policy) and developments around artificial intelligence and full autonomy, UAV technologies will become a mainstream tool allowing users to obtain and use vital spatial, agronomic information in a proactive manner.

Given the wide variety of precision farming technologies and techniques that are already available, UAV technologies must be developed to complement these and to target specific areas where the technology is most suited. This is particularly pertinent in relation to platforms that have sensing capabilities such as satellites, aircraft or tractor-based systems. A user should not have to select a technology to make a decision – instead, they should have access to the data independent of the source and be able to exploit it alongside other information to make more informed decisions (using a data science approach).

Whether UAV technology is used as a machine or a data source, it must be simple and easy to use ('plug and play') and provide actionable agronomic data and intelligence, with clear and proven value and benefit. Understanding and proving how this technology can be used by agricultural users alongside other precision farming techniques and data sources will ensure it is exploited correctly and therefore become an 'invisible' yet vital tool in helping the sector overcome production and environmental pressures.

5.4 Satellite Applications Catapult Involvement

The Satellite Applications Catapult is well placed to support and assist the UAV and agricultural sectors in the development of UAV technologies for use alongside other data sources, in order to ensure timely, proven and valuable state-of-the-crop intelligence is delivered to agricultural end-users. The status of the Catapult as a neutral, not-for-profit organisation with industry-leading technical and business expertise offers a unique opportunity for both the UAV and sectors such as agriculture to engage with us and to develop new technologies and services. The Catapult can support users through collaboration to develop existing solutions or to create innovative new ones.

The Catapult has the following enabling credentials:

- **Sector knowledge at a global level** – The Catapult is working with stakeholders from across the agricultural sector around the world. This provides a unique opportunity to develop and exploit market opportunities at a range of scales, from the farm to national level.
- **GNSS and communications** – The Catapult has expertise in resilient GNSS and satellite and terrestrial communications technologies, which are essential for safe and effective future BVLOS operation of UAVs.
- **Satellite technology and missions** – The low power technology being integrated into small low-cost satellites is directly applicable to UAV platforms. Use of this alongside the disciplines and approaches for management of satellite missions for operational purposes are applicable to the future automated traffic management systems for BVLOS UAVs.

- **UAV expertise and capability** – The Catapult has access to airframes, operational capability and the ability to design and manufacture new technologies where required.
- **Data and analytics** – Cutting-edge remote sensing expertise across available sensing technologies enables the Catapult to extract and generate critical intelligence. We routinely access data from an enormous range of platforms and sensors to create information.
- **Networks and systems** – We are developing IoT based solutions and sensors to capture in real-time critical measurements related to soils and the crop canopy. We are developing these networks and systems along satellite and UAV technologies to create integrated farm applications.
- **Application and visualisation** – From the creation of IT infrastructure and data platforms, to 3D augmented reality, The Catapult is developing innovative solutions to hold, process, serve, and display data to consumers.
- **Business Innovation** – Commercialising the technologies and applications to bring early stage ideas to market, using business and design expertise and connections with the finance industry.
- **CEMS** – Our Climate, Environment and Monitoring from Space (CEMS) platform is a purpose-built facility offering space-based climate change and EO data and services. CEMS is designed to give users access to extensive data holdings and a range of applications, tools and services that help them analyse this data more effectively.
- **SEDAS** – The Catapult is the UK access point for data acquired by the ESA Sentinel Programme through the Sentinel Data Access Service (SEDAS).

Given our expertise, facilities, infrastructure and access to data, the Catapult – through our Sustainable Living Programme – is actively working with users from the UAV and agricultural sectors to understand how UAV technologies can be appropriately used to create and/or deliver actionable, critical agronomic intelligence. This is being achieved through undertaking collaborative projects that bring together different technologies, technology providers, and data sources with users from different parts of the agricultural sector to link the information with decision making and value.

Our direct involvement with the UK Pathfinder programme will enable us to shape the direction of UAV policy, regulation and operation in the UK. Coupling this with platform, data and analytical developments, we will support the enabling of UAV technology as a precision farming tool, ensuring it is capable of providing agronomic information with proven value.

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⁶ Front and back page image showing Callen Lenz Consulting 'G2' UAV



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