5G Rural Integrated Testbed

D3.2 Final Report - Arable Use Cases

Acronym:	**5GRIT**
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1 Executive Summary

- there are clear economic benefits for the provision of a mobile broadband network in agriculture;
- the economic benefit in arable production is significant if combined with precision agriculture techniques;
- a 5G network is able to convey images and high quantities of data from fields where there is currently little connectivity back to farm offices;
- farmers preferred to focus on rural connectivity than the specific uses cases being developed by 5GRIT;
- the benefits of enhanced communications in rural communities is significant, especially in the areas of health services and approaches to combat isolation and loneliness.

2 Introduction

This report is to be read as an addendum to the interim final report produced in April 2019. It is not intended to repeat information contained in that report.

http://www.5grit.co.uk/wp-content/uploads/2019/07/D3.13-Interim-Final-Report-Agriculture-V2.pdf

This paper covers the period from April to September 2019 of the 5GRIT project extension, funded by the Department for Digital, Culture, Media and Sport as part of the 5G Testbed & Trials Programme. This extension was necessary to cover a full crop-growing season, which runs from September of one year to August of the next. This enabled us to assess the yield achieved in the monitored fields. This data formed the basis for a separate report called “A year in the life of a wheat crop”, which will form part of this report.

3 Research Question- what we set out to achieve

Can 5G deliver productivity improvements through smart agriculture for upland livestock farmers and lowland arable farmers through improved monitoring and analysis of data gathered by drones and analysed in the cloud?

3.1 Achievements

Overall, the project has achieved the original objective as set out here. We were able to demonstrate potential use cases for both arable production as well as animal monitoring. This included the use of drones and multispectral imagery captured via the drones to provide more accurate information to make better agronomic decisions in arable crops. We were able to show this on three fields and one crop - winter wheat - but this was adequate to illustrate the potential.

For the animal monitoring trial, we were able to capture still and video imagery of sheep on a highland fell area, enabling our consortium partner Kingston University to derive algorithms to count and monitor the sheep remotely.

This is a learning curve for the algorithms and, as detailed in D4.3 Final Report - Livestock and UAV Use Cases, we were able to increase the accuracy of counting from 55% at the beginning of the project to around 85% at the end. With continued work and algorithm 'training', this level of accuracy can only increase.

Within the project, we were able to achieve objectives aligned with a 'test-bed' approach. We proved that:

- the chosen use cases could be implemented and were of some benefit to the farmers;
- that the technology could work in the field - we successfully transmitted data heavy media files from the trial fields near York to the Precision Decision offices and then further on down to Kingston University - this last step using conventional internet;

Figure 1: 5G mast and equipment installed at the Precision Decisions offices north of York

- we were able to discuss the use cases with a small selection of farmers to gain some initial feedback;
- we were able to discover additional use cases beyond the direct scope of agriculture which led to very positive discussions focused on rural isolation, loneliness and associated mental health.

4 Implementation

4.1 Arable production

We chose a site near to the Precision Decisions offices near York to which we would have access all year round. Our intention was to follow the crop growth all year from sowing in the autumn, through crop protection and nutrition in the spring through to harvest in late summer. We would then choose the 4 or 5 main decision points a farmer would normally make over that period and take drone imagery at those times. These images would then be processed and used to assess whether better agronomic decisions could be made as a result. Details of this are in the separate “Year in the life of …” report.

The farmer we worked with found the information to be useful. It was unclear, however, whether he felt he could make better decisions as a result of the images and information we made available. This is discussed further in the Key learnings section.

4.2 Drone imagery and agronomists

Data collected by drones provides a different ‘view’ of the field and the crop growing in the field. We flew the fields the same way each time following a set pattern as shown.

Figure 2: Drone map of test field

In this way, data and information could be retrieved with little or no variability with reference to flying height or direction. Images were then collected throughout the growing season.

Figure 3: emergence of the crop

Figure 3 shows the usual view an agronomist or 'crop-walker' would have of a field in the autumn post planting after emergence of the crop. This is a critical stage in the crop life-cycle as deficiencies can be corrected at this early stage if recognised.

As can be seen, the crop and field look very uniform here.

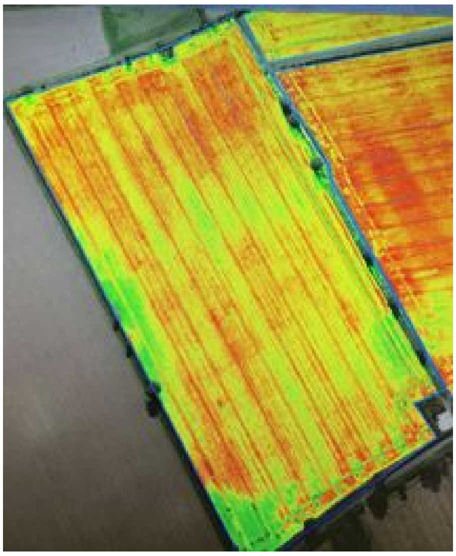


Figure 4: multi-spectral image of the test field

Figure 4 shows a multi-spectral image of the field at the same time of year. As you can see, in-field variability is easier to visualise and with such an image, we are able to quantify the variability. The colours represent differing health status for each plant, with red being less healthy than green. The red stripes are the tractor tramlines where there is no crop at all. Red between the stripes means that the crop in those areas is stressed. It may need more nutrition than other areas to compensate.

Such images enable the farmer to manage his input regime in an optimal manner, which saves costs and protects the environment from excessive applications.

In addition, these types of images can be used to enable growers to better predict future crop yields. Without a quantifiable image of variability, the farmer relies on historical records and his or her intuition to estimate the future yield. With a quantifiable image, the farmer can optimally plan the associated input regime based on the projected outcome.

Later in the year, crops can be monitored better from an aerial aspect as the following sequence of images show (taken from Year in the Life report):

Figure 5: The crop on 3rd May 2019 taken at ground level.

Figure 5 shows the crop from the perspective of an agronomist or farmer. The crop looks very uniform and healthy. Very little if any variability can be perceived.

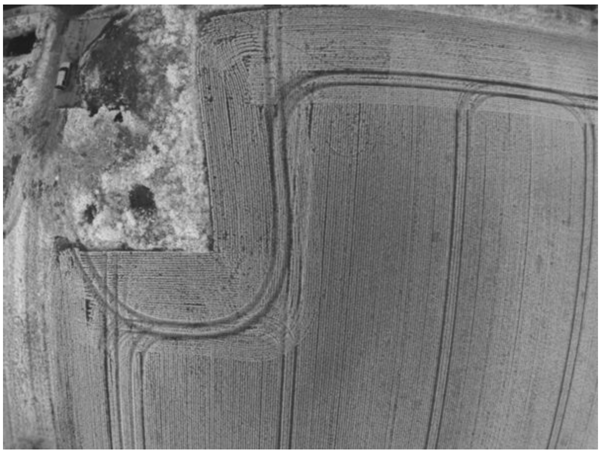


Figure 6: Drone image of the test field showing shadows

The drone image of the same field is shown in Figure 6. There are shadows on the image which could depict variability, but the image needs more processing to assess and quantify that variability.

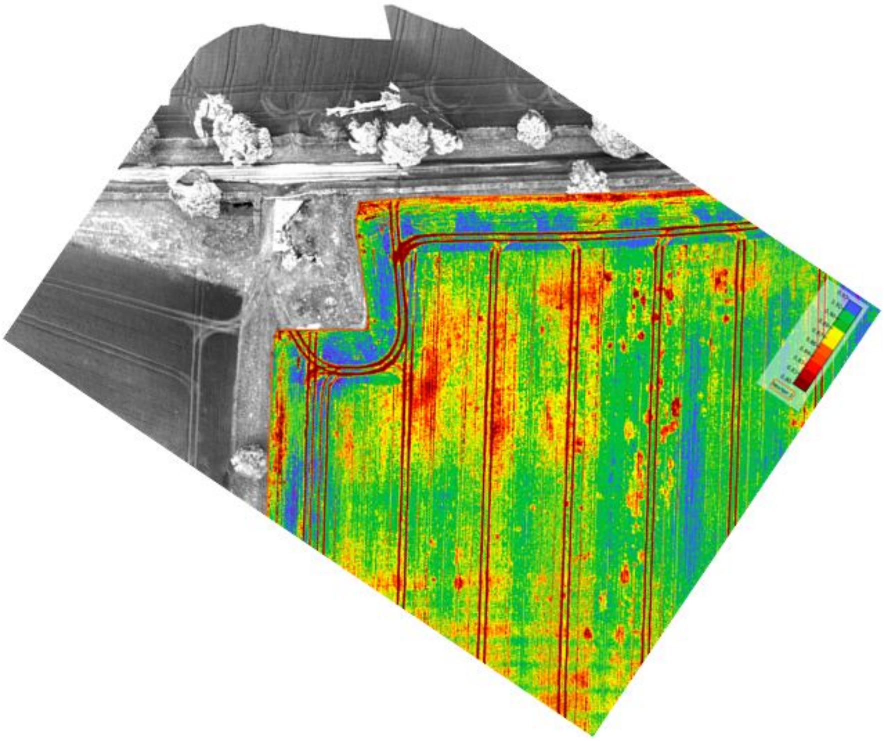


Figure 7: Processed drone image of the test field

Finally, figure 7 shows the processed image which very clearly shows the in-field variability. The blue areas are where the crop was 'double drilled' so has a higher plant population than the rest of the field.

The red areas show places in the field which are effectively reflecting less 'greeness' back to the camera. This indicates either a lower plant population or that the plants are under more stress. The scale on the right permits the grower to quantify these differences.

4.3 Use of imagery to optimise inputs

This level of detail, now quantified, can be used by the grower to optimally plan and apply their inputs, especially fertiliser. The goal of the grower is to minimise the variability across the field and this is achieved through the use of variable rate applications. Many modern tractors, sprayers and fertiliser spreaders are equipped with special controllers which allow them to apply fertiliser in a variable manner according to a set prescription map.

Figure 8: Prescription map

Figure 8 shows an example of a prescription map, which are maps used by the tractor and spreaders to apply fertiliser in a spatially variable manner.

This prescription map is derived from the associated multi-spectral image, which is shown in Figure 9 below.

The rate of fertiliser is aligned with the processed image which shows more clearly the variability in the field.

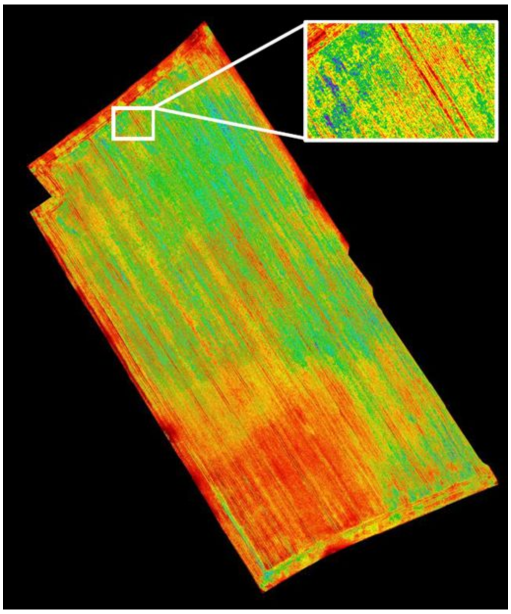


Figure 9: Processed image showing the multi-spectral imagery associated with in-field variability

In effect, the colours are showing variability in the ‘greenness’ of the crop, which is an indication of the health and nutritional requirements of the crop.

The inset shows the fine detail of the processed image. The red lines represent the tramlines which are the channels made by the tractor as it passes through the field. There are no plants in these channels which is why they show bright red.

4.4 Effect of variable rate applications

Figure 10 shows how inefficient application of valuable nitrogen fertiliser has resulted in one area of the field - the nearside - receiving too much nutrient. This has caused the plants to grow too long in the stem and after a storm, they lodge or fall down. The far side of the field has received the optimal amount and has remained standing.

Figure 10: A field showing the effects of inefficient application of nitrogen fertiliser.

The practise of applying fertiliser variably is intended to even out the variability within the field. This has a number of positive effects:

1. It can reduce a phenomenon known as ‘lodging’ in which too much nitrogen is applied to the crop, which elongates the stems. In a storm or heavy rain, the plants can bend and ‘go down’ or lodge on the ground. This in turn affects the growth and ultimately the yield of the crop. Applying fertiliser in a variable manner reduces this risk.

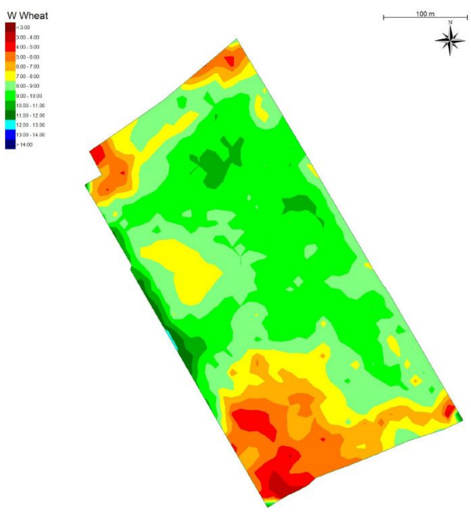
2. A farmer can decide which regime to follow. At the beginning of a season, while the crop is still developing, the farmer may apply more fertiliser to poorer areas to help them ‘catch-up’ with the rest of the field. Later on in the season, the grower may decide to apply less to these areas, for example a late nitrogen dressing for protein content, as the overall yield potential in those areas is lower. The images quantify the variability - farmers can then make much better data driven decisions whichever regime they chose to

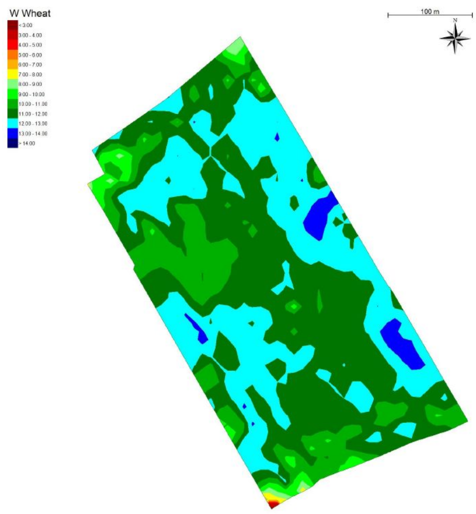
follow.

3. Applying fertiliser in this manner often means that an overall reduction of applied product can be achieved. This clearly has a positive effect on the environment as only that amount of nitrogen which is required is applied and there is less ‘wastage’.

4.5 Effect on yield and profit

Yields can be affected significantly through the use of these images. The two images below show these effects. The image on the left shows the wheat yield in 2017, the red areas showing the poorer areas of the field, where yield averages 3-4 tons per hectare and the dark green depicts areas where the yield is 10-11 tons per hectare. The average yield across the field in that year was 10.4 tons per hectare. Variability of yield is very pronounced.





The image on the right shows the actual yield in August 2019 following the work done with this project. Fertiliser was applied variably in accordance with the imagery from the drones throughout the season as well using data from other sensors. The range of yield this year - in other words, the variability of the yield - is significantly lower, with much more of the field being ‘normalised’. This has the effect of not only making it easier operationally for the harvester to combine the crop, since the crop is more uniform, it also has an effect of optimising the profit margin across the field. A field such as this is easier to manage as the variability is minimised and controlled. Inputs are optimised and the margin per hectare greater than a field showing higher variability.

The blue areas depict yields of 13-14 tons per hectare and the light green areas 8-9 tons per hectare. Even allowing for variability between the seasons, it is clear that a field managed for variability generates higher yields and provides better margins for the farmer.

At a wheat price of £50 per ton, the difference in average yield between 10.4 and 11.7 tons per hectare equates to £195 per hectare increase in revenue, or across the whole field, an increase of £2,395.

4.6 Animal Monitoring

The animal monitoring trial provided slightly better results. The farmer we engaged with indicated that the technology would save him considerable time each day. We learned that, especially in the summer months, when the animals are on the extensive fell areas, the time taken to know the whereabouts of the animals can be up to three hours. Using the drone captured imagery combined with the algorithm developed by Kingston University, we were able to demonstrate that we could let the farmer know of the number of sheep in the field or on the fell without him having to go out. This does not directly save him any money as we are giving him the same data. However, he can use the time saved to either perform other tasks on the farm or supplement his farm income with non-farm work.

The value for this is difficult to estimate but if we take an hourly rate of £10 per hour, the additional income could be up to £30 per day, £150 per week or £600 per month, which placed alongside the low margins achievable in hill-land sheep farming, is considerable.

The farmer further discussed with us an additional benefit which concerned the welfare of his animals. He was very keen to express to us that he feels responsible for every single animal on his farm and under his care. He felt responsible to ensure the animals' welfare at all times. The drone imagery can help him do this more efficiently.

Sheep tend to be gregarious and flock together, so the drone imagery can identify animals which are located away from the flock. This could indicate a sick or trapped animal, which the drone imagery can potentially identify quicker than the human eye could see the issue. The imagery can also provide the exact location of the animal in question.

An available drone could be sent out to ‘scout’ the animal after which the farmer can decide the next best action. This would save him time again in both searching for the animal and also deciding what remedial action to take.

5 Commercialization

The infrastructure required to perform this project represents a fairly high level of capital expenditure. The towers for the 5G connectivity and the drones themselves are unlikely to be items a farmer would consider acquiring. Hill sheep farmers in particular could not justify this level of investment. larger arable units may well be able to and would possibly consider acquiring their own equipment.

However, the commercialisation of these services requires more than the acquisition of a drone. The Civil Aviation Authority requires drone pilots to be adequately trained and qualified, and as part of the project, Precision Decisions were able to train and qualify two employees as drone pilots.

We feel that a more likely commercialization scenario would focus on service providers owning the drone equipment and delivering the data and insights to farmers for a service fee. This will help keep the cost per hectare down to manageable levels as many farms could be flown in one operation. The cost and organisation of training a drone pilot would not have to be borne by the farmers, as the pilots would be employees of the service company.

Similar services are already provided, for example, soil sampling, where a service provider takes the sample and another performs the chemical analysis of the soil. The service provider returns the results along with a recommendation to the farmer for a fee.

5.1 Future commercial usage

We do not envisage that farmers will own their own drones. Rather we see that this technology will be picked up by service providers who will then ‘sell’ the information and insight to the farmer for a fee. In this way, the grower will not have the capital costs and will not have to train as a drone pilot.

Costings are difficult to evaluate at this early stage, but the following could be a hypothesis.

To provide a drone imagery service, the following will be required:

- Drone: £50k depreciated over 5 years = £10k per year
- Multi-spectral camera: £10k depreciated over 5 years = £2k per year
- Image processing: estimated at £15k per year
- Labour: estimated at £35k per year.
- Other costs (admin and vehicles) £5k per year

In total, annually, we estimate there would be a cost of approximately £67k to run the service. To be commercially viable, we estimate such a service would need to cover 60,000 hectares to ensure the cost per hectare is close to £1 to £1.25.

We think an acceptable commercial price would have to be close to £1 per hectare flown.

Item	Capital Cost	Annual cost
Drone	£ 50,000	£ 10,000
Camera	£ 10,000	£ 2,000
Processing		£ 15,000
Labour		£ 35,000
Admin		£ 5,000
Total		**£ 67,000**

Hectares flown	Cost per ha
50,000	£ 1.34
66,979	£ 1.00
75,000	£ 0.89
100,000	£ 0.67

6 Key Learning Points

6.1 Arable

The main learning from this work package was that the use cases were interesting but not compelling for the farmers we talked to. A small sample questionnaire indicated that while the chosen use cases were interesting, the main driver for the farmers was simple connectivity in all rural areas. They stressed that if we provided the connectivity, they would develop the use cases.

The main arable farmer we dealt with was interested in the images and insight provided but it was unclear whether these changed his operational decision making. As we were dealing with an already fairly progressive farmer, this is perhaps not too surprising. Certainly a key learning here is that this type of technology, which provides growers with additional data and insight, will take its time to be recognised as a benefit and for these to be quantifiable.

The project helped us to clarify and quantify the economic benefits of variable rate applications which were achieved using the drone imagery.

6.2 Animal production

The key learning here was that the farmer was equally interested in the welfare of his animals in addition to productivity factors. The hypothesis that animal health costs could be reduced as a result of better monitoring could not be proven as we were unable during the project time-frame to monitor the farmer's use of animal medicines. This would need to be done in a future project with more participants. There is, however, a generally accepted goal within the sheep production industry that a reduction of 10% is possible through various means.

The farmer helped us understand the daily work associated with animal monitoring and the length of time it takes to do this. This time factor helped us build a reasonable use case.

6.3 Rural Connectivity

The ability to both contact a worker operating in a remote location as well as for them to call out from that location was seen as essential.

The declining workforce (dropped from circa 900,000 in 1949 to about 180,000 today) has resulted in significant changes on farms.

Additional changes are:

- people working on farms spend large amounts of their day alone;
- Poor communication links mean that workers cannot easily make outgoing calls, neither can they be reached;
- Modern machine technology means that farmworkers can often perform their work with little to no supervision – they have no operational need for contact;

This can all lead to isolation.

Farming practises have changed over the years, which are exacerbating this issue. The weekly Farmer's Market was a place where farmers, their wives and farmworkers could get together and discuss not only farming, but all sorts of other aspects of rural life. Theirs was an interactive, rural community and everyone was there to help each other. These markets and the associated interactions have largely disappeared, leaving a void in rural interaction. In addition, the age of people living in rural areas is steadily increasing, with the average age of the UK farmer at 59 as younger people leave for urban life.

The additional stress on the farming community to produce high quality food at the lowest price possible puts financial pressures on the entire farming community. We are not claiming any 'cause and effect' relationship, but there has been a report published by the Farm Safety Foundation which indicates that of people working in agriculture in the UK, one person per week takes their own life. Isolation and loneliness have been recognised as important factors in mental health issues, and the trends in agriculture leading to more isolation certainly cannot help this.

This aspect of rural connectivity developed from within the project and was not a main objective from the start. We are proposing to continue the work in this area in the subsequent DCMS project call for Rural Connected Communities.

7 Results

The key results from this workpackage are:

- enhanced connectivity from 5G based mobile broadband can improve agricultural productivity both in arable farming as well as livestock production;
- we were able to collect image data throughout the growing season and transmit this back to both the PD offices as well as Kingston University;
- Kingston University were able to develop image algorithms to automatically identify and count sheep on a fell hill-side as well as beginning to assess a capability to count plants early on in the growing season;
- We were able to prove that drone imagery can be effectively used to better manage in-field variability and improve both yields and margins;
- We were able to develop further use cases, broadening out into aspects of rural life and society, such as mental health issues, which can equally be addressed by connectivity, however the use cases are not easy to quantify in terms of direct economic benefit;
- adoption of the insights provided will take time to become accepted by farmers;
- the time factor for animal monitoring is an important factor for sheep farmers and one where drone imagery can help;
- farmers and others in rural communities are keen for the general provision of a good communication network in their areas;

8 Future Work

The project provides an excellent foundation for further work in how connectivity can positively enhance lives and businesses in rural areas. It showed how the use cases go beyond agriculture and affect the fabric of life in a rural community.

For agriculture, future work can include the calculation of how variable rate and precision agriculture makes economic sense. More work can be done to show growers that the pay-back period for the expense can be just a few years or even just one good season.

To potentially further the development of these use cases, several of the consortium partners intend to apply to continue the work as part of the DCMS funded Rural Connected Communities initiative.

9 Conclusion

The project set out to examine the use cases in agriculture for enhanced mobile connectivity as provided through a 5G network. We examined two cases, one in animal production and one in arable. In both cases we were able to show economic benefits of connectivity and near-real time data and image transfer.

We conclude that there is potential to improve agricultural productivity through the provision of enhanced connectivity, but that the adoption of the developed services may well be slow.

Costs for infrastructure in rural areas are high and an incentive scheme will be required to alleviate this. Mobile network operators are unlikely to see the economic benefit of installing the infrastructure.

The benefits go beyond agriculture and more work needs to be done to evaluate these in rural village communities.