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Precision agriculture at the NPL

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This *Electronics Letters* guest feature is an overview of activities of the Precision Agriculture Group at the National Physical Laboratory, UK, led by Richard Dudley. Precision agriculture uses sensors, robotics and data analysis to automate and precisely target agricultural activities – for example by employing a fruit picking robot that checks every fruit for colour, size and blemishes before harvesting it. The group is engaged in multiple and diverse projects, all funded by industry and aimed at producing industrial solutions for immediate field deployment. The group has been active for 8 years, and in that time has delivered more than ten projects to industrial customers.

The agricultural technology (agritech) industry's desire to adopt high-tech solutions is driven by the conflicting needs to increase productivity whilst reducing resource inputs. Worldwide demand for food has been growing steeply since the beginning of the industrial revolution in the mid-18th century due to expanding populations and rising prosperity. Until very recently, traditional agriculture has met this demand by expanding land use, massively increasing inputs – irrigation, fertilisers, pesticides, herbicides, greenhouses, high-energy feed and pharmacological supplements for livestock, massive deployment of heavy machinery – and by relying on tried and trusted farming methods to maximise productivity. Going forward, however, these solutions are no longer sufficient; and moreover, are seen as undesirable. The great majority of the land area suitable for agriculture is already under cultivation; widespread soil degradation and water shortages are limiting yields; regulatory requirements to reduce pollution as well as diminishing returns are putting constraints on the use of chemicals and pharmaceuticals; and concerns are being raised over the environmental costs of livestock farming. And perhaps worst of all, waste in the supply chain accounts for up to 20% of all grown produce. For all these reasons, the agritech industry has turned to R&D to provide high-tech solutions that can enable it to meet the conflicting demands of food production, reduced resource usage, and environmental regulation.

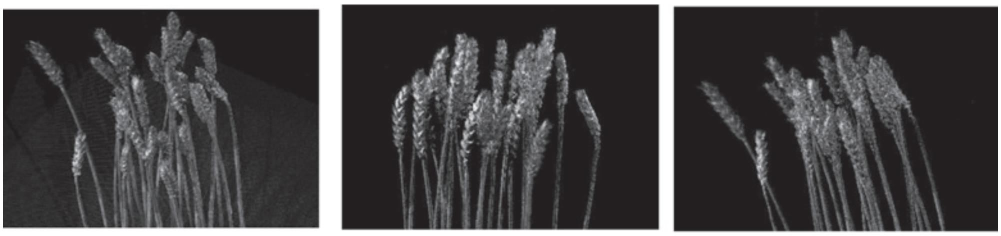
Precision agriculture is a very active multidisciplinary field, bringing together electronic and mechanical engineering, environmental science, biotechnology, plant science, health & nutrition, computer vision & robotics, and automation. It requires the active participation and engagement of many different industries: horticulture, seed manufacturers, food producers, supply chain, supermarkets, etc. In the UK there are currently around 50 groups working in this area; and to support this activity the UK government has set up 4 knowledge transfer network (KTN) epicentres.

The precision agriculture group at NPL makes use of many types of sensors and techniques covering a wide swathe of the electromagnetic spectrum from microwaves to optical light, as well as ultrasound. Computer vision and machine learning techniques are employed for data analysis, 3D imaging and image recognition; and robotics are utilised to automate these processes.

The group targets projects where its expertise can make immediate significant impact, and where the developed technology can be rapidly implemented and rolled out by the customer.

The efforts have focused on four types of projects:

• Imaging technology to facilitate breeding of new crop varieties (wheat, barley, maize). Imaging plants as they grow in the field allows to track their performance in order to select the best varieties for propagation (phenotyping).



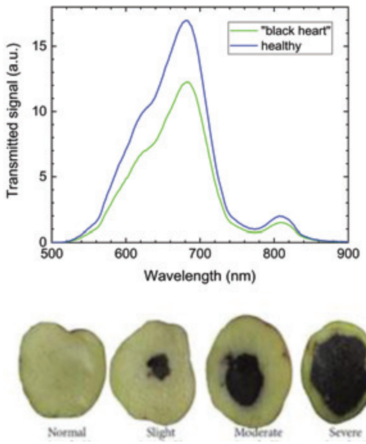


Figure 1 (Top): Images of wheat plants growing in a field, all part of a 3D image viewed from different angles, obtained by structured light laser scanning employing a single laser source and camera positioned on a rig above the plant

Figure 2 (Middle): Left: Photographs of strawberries in various states of ripeness. Right: False-colour images of the same strawberries derived from those photographs using a colour look-up table, showing correct identification of ripe areas.

Figure 3 (Bottom): Top: Optical transmission spectrum of a clean (grade 1) and damaged (grade 3) potato (normalised for path length through the tuber). Bottom: Images of "black heart" damage in potatoes, provided by Xiaogao Li from Southeast University, China.

• Automated harvesting of produce to reduce costs and increase yields (strawberries, raspberries, brassicas).

• Sorting/grading of produce to reduce wastage (potatoes, apples, avocadoes, oranges).

• Monitoring livestock condition to increase the efficiency of rearing animals by precise individual control of feed, and to track their welfare and readiness for slaughter (pigs & cattle, dairy).

Phenotyping: wheat

Wheat is one of the most important crops for human nutrition, accounting for 20% of calories consumed worldwide. In the last 20 years, however, wheat yields have stagnated at around 9 tonnes per hectare; and in some years unfavourable climatic conditions have reduced yields further. The rising demand can only be met by developing new varieties that will combine higher yields with better resilience to pests, diseases and environmental challenges. Phenotyping – an essential step in breeding new crop varieties – is currently done by harvesting and testing a sample of plants from a testbed at set time intervals in the growing cycle. This manual process is slow, expensive, and most importantly the scope and detail of the data is severely limited by the testing interval and the number of plants collected.

The effectiveness and efficiency of phenotyping can be greatly increased by non-invasively imaging every plant in the testbed at frequent intervals throughout the growth period, using image analysis to quantify and track their individual performance. To achieve this, it is necessary to obtain 3D images of wheat ears growing outdoors under a variety of illumination conditions, and to reliably quantify the size of the ears from those images. This is a very difficult task, due to two

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Figure 4: A piglet at a farm where fat layer sensors are being tested.

main challenges: reliably differentiating the ears from the stems and leaves (given that they have similar colouring and geometry); and evaluating the volume of the ears in widely differing positions and orientations. It was found that the most effective approach is to employ structured light laser scanning, which overcomes the issues associated with ambient lighting. A laser projects a known light pattern onto the object, and the reflected light is recorded by a camera; distances to different parts of the object are calculated from the distortions in the pattern. The geometry of the object can then be derived from this data. Fig. 1 shows an example of such image of a wheat plant taken in a field, with the scanner and camera positioned on a rig above the plants: the single source and camera produce a full 3D image. From this 3D image the volume of the wheat ears can be calculated.

Automated harvesting: strawberries

Strawberries are ever popular with consumers and are a high value fruit produce. However, harvesting strawberries is labour-intensive and requires a degree of skill, because the fruit is delicate and easily damaged by bruising, and moreover must be harvested at the correct stage of ripeness since both under-ripe and over-ripe fruit is unattractive. Automated fruit picking by robots is therefore an attractive solution. The main challenge lies in employing computer vision to locate the fruit among leaves and to determine its degree of ripeness, and to do so rapidly and reliably under variable ambient illumination and partial scattered shade in the field conditions.

The adopted solution employs a full colour camera and a look-up colour table. Images of fruit are recorded simultaneously with those of the colour table under the same lighting conditions. Strawberries are identified by colour against the background of leaves and non-plant objects and are segmented by colour coding into ripe/unripe regions. The degree of ripeness is determined by the ratio of ripe/unripe areas. Fig. 2 (right) shows examples of colour coded (false colour) fruit images of various degrees of ripeness. Comparison with photographs of the same fruit in Fig 2 (left) shows that ripe fruit are correctly identified.

Produce sorting: potatoes

Potatoes are one of the most widely consumed vegetables, with the annual world production of around 400 million tonnes. Harvested potatoes are often stored for prolonged periods. If they are stored incorrectly, with insufficient air flow around the tubers, the cells at the centre of the tuber asphyxiate and die. The necrotic tissue (dead cells) is black – the potato develops “black heart” (Fig. 3). If a sufficient volume turns necrotic, enough gas is produced to create a cavity at the centre of the tuber. Potatoes affected by “black heart” are unsuitable for consumption and must be identified and discarded. Currently the only testing technique available is to slice the tuber for a visual check. If damage is found, the whole batch is discarded, because potatoes are a low-value produce. A rapid, non-destructive, inexpensive method for identifying potatoes damaged by “black heart” would greatly reduce crop wastage.

Optical transmission using different wavelengths of the electromagnetic spectrum was tested to detect “black heart” in potatoes, from microwaves to the visible spectrum. It was found that transmission of red light around 690 nanometres can be used to detect the presence of “black heart”, as seen in Fig. 3; such transmission tests can be performed quickly and inexpensively by using a laser diode source and a photodiode detector.

Livestock condition: pigs

Concerns are rising regarding the environmental burden of livestock farming, the welfare of farmed animals, and the use of antibiotics. Producers seek to address these in part by reaching for tools which enable them to reliably monitor the condition of their livestock. Monitoring individual animal’s health will allow early intervention, improve welfare, and reduce the usage of pharmaceuticals. In particular, tracking fat/muscle ratios will enable the appropriate adjustment of feed levels in order to reduce both feed consumption and the amount of waste produced; and this is also a critical factor in judging readiness for slaughter. Currently, farmers monitor their animals by relying mainly on experience and familiarity with their appearance and behaviour, and on frequent and close observation. They recognise, however, that such observation is not always reliable, which often leads them to over-feed and over-dose their livestock. A non-invasive technology that would allow routine monitoring to be carried out rapidly, inexpensively and reliably will therefore be of great benefit.

Pork meat is in high demand both for direct consumption and as a base for a large variety of processed meat products, with nearly a billion pigs raised annually worldwide. Pigs develop a layer of fat under their skin, and the thickness of this layer is an important factor in judging the condition of the animal. It is highly desirable to be able to monitor fat layer thickness at various points on the pig’s body non-invasively, rapidly, without distressing the animal, and *in situ* using a hand-held device. It is known that muscle tissue and fat have different dielectric properties which are strongly frequency-dependent. A compact sensor device utilising these variations has been developed and tested on slaughtered carcasses. The next phase of the project will aim to validate these results in living pigs; and if confirmed, a handheld sensor will be built to measure fat thickness in pigs.

The future of agriculture

Precision agriculture was included in a recent Frost & Sullivan report on “Top 50 Emerging Technologies”, which noted in particular that it is “a promising strategy to solve the food-water-energy nexus”. This overview of projects undertaken by NPL showcases some examples of technology applications that can improve the quality and quantity of food delivered to consumers while also reducing wastage and costs to the producer and increasing the overall efficiency of food production. A key aspect of precision agriculture is that it employs a wide variety of technologies – as demonstrated by the projects described – and is broadly multidisciplinary, requiring contributions from many fields of engineering. Also, and crucially, it is strongly focused on real-world applications, always working with customers to provide technological solutions to their problems.

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