

## Feature

# Robots in agriculture

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### Abstract

SILVER, the special interest group on advanced robotics and intelligent automation, is holding a series of meetings on applications in different sectors of industry. The May meeting was held at the Silsoe Research Institute in Bedfordshire. Speakers from Silsoe, as well as from universities and industry, reviewed a number of applications, current and potential, and some systems were demonstrated during the lunch break.

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Welcoming SILVER members to their meeting at the Silsoe Research Institute was the project leader of the Robotics and Automation Group at Silsoe, Dr Nick Tillett, who began by putting present-day farming methods into their historical perspective.

Back in the 1730s Jethro Tull introduced planting crops in rows so that his workers could carry out cultivation between the rows. The introduction of agro-chemicals since the war, using chemical herbicides and insecticides, has made such cultivation largely superfluous. But in recent years there have been changes in attitude. Herbicides are becoming more expensive, particularly in relation to "minority" crops like, for example, cauliflower or sugar beet, where it is not worthwhile for the big agro-chemical companies to develop suitable herbicides. In addition to economic factors, environmental and food safety considerations are increasingly important. Certain crops are therefore routinely mechanically hoed between the rows.

There is therefore a demand for some form of automation of hoeing that would be accurate, fast, robust and able to work long hours. This last is particularly important because it is important to seize opportunities of weather "windows" when they come along.

Silsoe have developed a vision-guided hoe for cereals and sugar beet that can be used for inter-row cultivation (Figure 1). It uses a signal-processing approach to row-finding. A forward-looking monochrome CCD camera scanning horizontally across the rows detects a periodic pattern in grey level, and a bandpass filter locates the rows, even in the presence of shadows and random weeds. For row tracking, eight horizontal scan lines each provide an observation for the Kalman filter based tracker.

Any lateral error between rows and the row of hoes is corrected by hydraulic cylinders, which move the hoes sideways. Initial work has been done using a Garford steerage hoe, field tested in a crop with an inter-row spacing of 0.22m. Results have shown that the method is effective even in the presence of shadows, with a standard error of 15mm at 6kph when hoeing cereal crops, and Tillett reckons that it should be possible to operate a good deal faster.

Work is continuing on the effects produced by a low sun on tall crops, and on the performance of the system on young sugar

**Figure 1** Computer-guided hoe for weeding uses video camera to steer between crop rows



beet crops, which have much less prominent features than cereal crops.

Further work, funded initially by the Biotechnology and Biological Sciences Research Council (BBSRC), includes a study of robust autonomy for crop protection and data gathering. The aim was to provide spot treatment of transplanted cauliflowers, using a small tool frame Bomford tractor equipped for drive by wire, with a number of individual spray nozzles. The individual plants are located within and between rows for spot spraying, and in order to do this the position of the vehicle has to be tracked. Again a monochrome CCD camera with NIR filter is used, looking forwards and down. A chain code extracts features specific to the required plants using feature classification on the basis of size and position matching. The features are matched with the predicted plant position and the probability of a match is calculated. Multiple observations of plant positions are merged to a single pseudo observation using a recursive least squares method. This pseudo observation contains information about the direction of heading and offset, which is passed to an extended Kalman filter. The position is tracked for purposes of navigation and treatment control.

During experimental work, dye was put into the nozzles to check the accuracy of the spraying, and a match within 25mm was achieved 95 per cent of the time.

Further work is continuing on evaluation of improved distinguishing of crops from weeds; on the improvement of spot treatment, particularly for minority crops; on development of crop/weed mapping; and autonomous field walking for data gathering.

## Out of the factory

Dr David Hopper, Robotic Systems Manager at UK Robotics, summarized the detailed report prepared by the British Robot Association for the Ministry of Agriculture, Fisheries and Food, entitled *Out of the Factories and into the Fields*. The report, presented to the Government in September 1998, was based on an international fact-finding mission, carried out by a team from UK Robotics on behalf of BRA, to study the status of advanced automation and robotics in UK agriculture and to make recommendations regarding future action. Dr Hopper took the opportunity to thank the research community for its assistance in the compilation of the report.

Part 1 of the report offers a review of robotics and automation in UK agriculture and worldwide, with present and projected research, and presents the investigators' conclusions and recommendations. There is also a very large Part 2, surveying in detail the status of advanced automation and robotics worldwide.

The investigators set out to identify where gaps in the available technology or its applications existed and needed to be filled to meet future needs of UK growers and farmers. Implicit in the study was the idea that UK farmers and growers would prefer to buy UK-made equipment if available, and those manufacturers were looking for new market openings.

The study aimed to examine the competitive position of the UK in terms of current and potential use of robotics and automation as applied to field crops, protected crops and intensive livestock production. It also sought to identify and separate long-term research topics from pre-competitive research areas likely to bring commercial benefit in the shorter time scale; to identify where government funding was likely to lead to a significantly increased benefit to growers and farmers; and to highlight commercially available and near market developments.

Five countries in the world, including the UK, are active in agricultural robotics, and the team visited key centres in those countries. There was also desk-based research, largely but not entirely centred on the Internet, to find what was going on in the rest of the world. Part 2 of the report included all the international findings and was published for worldwide use as an incentive to international participants to take part in the study.

Part 1, including recommendations to the UK Government was issued only in the UK.

In France, some key work was going on, particularly in the south, funded up to the prototype stage by CEMAGREF (Centre Nationale de Mécanisme Agricole du Génie Rural et des Eaux et Forêts). The main application areas were, at different stages:

- Commercialized: grape and olive harvesting, apple and orange harvesting. The citrus harvesting machine had been withheld until market conditions changed. The apple harvesting robot had been withdrawn completely and discontinued.
- Prototype form: rose bush handling and grafting, robotic milking, quality systems for online handling and sorting of fresh products, automation of combine-harvesters.
- Research: nonchemical weeding, forestry and logging vehicle development, plant quality measurement, meat processing automation, monitoring of fertilizer levels in fields.

In recent years government funding has moved away from projects aimed at the development of autonomous systems and towards man-in-the-loop automation. This has caused a big hiccup in the work, said Hopper, with many researchers saying their work is not relevant any more, and they have had to re-group. He also suggested, from an outsider's viewpoint, that a lot of their work does not have a commercial focus.

### The Netherlands

Agriculture is key to the Dutch economy, and Hopper considered the work there to be among the top of the top group of five countries. The main application areas covered by research were:

- Commercialized: radish harvesting, pig slaughtering, flower harvesting (various), tulip bulb sorting, mushroom harvesting, bacon marking machines, quality assurance for flowers, robotic milking.
- Prototype form: asparagus harvesting, tomato harvesting.
- Research: cucumber harvesting, grapes tending and harvesting, greenhouse climate control.

Holland, more than any other of the countries visited, had a demonstrable track record in commercializing research results. It had been hoped to have a speaker from The Netherlands

Institute of Agriculture and Environmental Engineering, but she had been unable to attend.

It is a very high technology country, with a shortage of labour, so that, said Hopper, there is sometimes asparagus rotting in the fields because there is no one wanting to pick it. There are also very good links between researchers, users and suppliers. There are many very good high technology small and medium enterprises involved with the trade associations, and Hopper had the impression that there was much more under development than they could talk about because of commercial confidence.

### Japan

There are many robotics and automation projects relevant to the MAFF study:

- Commercialized: autonomous tractors, grafting robots, autonomous spraying vehicles, seedling transplanter.
- Prototype form or not quite yet commercialized: automatic silage feeding of cows, automated manure handling, harvesting fresh produce (cabbages, grapes, tomatoes, cherry tomatoes, cucumbers), autonomous vehicles (paddy fields), planting chrysanthemum cuttings.
- Research: autonomous tractors, grass cutting, harvesting fresh produce (cabbages, tomatoes, aubergines, water melons, oranges, strawberries), seedling thinning, autonomous vehicle for spraying in greenhouses, vehicle following system, weeding, robotic milking.
- Trials: trials were also being conducted on robot milking at three sites.

"Autonomous vehicles" sums up the real thrust of what is going on in Japan, said Hopper. Each centre the team visited was doing something on autonomous vehicles, and there was some overlap of activities with each group working separately.

There was very good industrial support for autonomous vehicles, particularly from Kubota. A strong driving factor towards automation was the increasing average age of farmers. Children did not want to follow their parents on to the farms, which were very small by comparison with UK farms.

Reflecting the small size of fields in Japan is the fact that they have an autonomous helicopter for spraying the fields because it is so difficult to get a vehicle in and out.

## USA

Here the picture was a little more confused, but one of the key interests was in global positioning systems (GPS) associated with autonomous vehicles. Areas of greatest interest reported in the study were:

- Commercialized: broccoli and cauliflower planting and harvesting machines, GPS based yield measurement systems.
- Prototype form or not quite yet commercialized: automated harvesting of grain and silage crops, autonomous tractors.
- Research: plant propagation, precision farming, oestrus detection in cattle, on-chip pathogen detector.

It seemed to the team that there was no clear strategy regarding development of automation and robotics in agriculture in the USA. Much of the funding was either internal to large companies or subject to strong pressure group influence, such as unions, trade associations and food retailers. A strong theme was the need to protect jobs.

## UK

Visits and interviews were conducted with organizations active in R&D in this area, and other organizations that might benefit from the technology developed. The overall impression obtained from the study was that the UK R&D measured up well with that being undertaken in the rest of the world. While some countries surveyed could boast some particular strengths that the UK could not match, the converse was also true. The UK was also strong in three broad areas that were not matched by other countries, and more importantly by The Netherlands, arguably our closest rivals in agriculture, economics and geography. These areas were precision agriculture and its practical implementation, plant scale husbandry and, although beyond the scope of this study, post-harvest meat processing. The UK had three applications near to market in robotic milking, mushroom harvesting (reported below), and fish processing; the first two in competition with The Netherlands and the third in collaboration with Iceland.

A summary of the robotics and automation projects found in the UK was listed as follows:

- Commercialized: yield mapping trailer, precision fertilizer application, GPS-based manual data logging, assistance

with the practical application of precision agriculture.

- Prototype form or not quite yet commercialized: robotic milking (near market), plant scale husbandry, mechanical hoe, robotic mushroom harvesting, development of yield mapping as a management tool in the production of arable crops, robotic cutting of pork carcasses into primals, robotic evisceration of pork, fish de-heading (near market).
- Research: semi- and fully-autonomous farm vehicles, robotic handling of delicate food products, robotic sheep dog, best management practice, remote sensing, improved digger control, tree climbing robot for date harvesting, expert filters to improve the accuracy of yield maps, force feedback and vision guided de-boning for beef carcasses, fat trimming for lamb chops.

Beyond these projects, a survey of Silsoe Research Institute's broader work revealed that many other projects could fall within the remit of this study.

Summing up its findings on the UK scene, the team set out what was available now, what was under product development and would be available within one to two years, what was under technology development and would become available in two to five years, and what was still in the area of longer-term research.

In locomotion, wheeled and tracked vehicles were already available, but walking vehicles for difficult terrains would not reach practical applications for several years. Sensors were already being used in environmental control for characteristics like temperature. In the near term sensors will be used in identifying and measuring field features, and in the medium term will be able to identify plant features, such as restricted growth. In the long term, more detailed measurement of plant and animal characteristics will be possible.

It could not be said that system integration was currently available for agricultural applications, and in the near future systems will only be programmed. In the medium term they can be expected to become sensor-based, and the "blue skies" work is looking to their becoming cooperative and behavioural.

We do not have to do much more work to produce workable agricultural robotic systems, said Hopper, but we did need to do a lot of development, to work with the people who use them, supply them and support them. That is

the major gap: it is not that we have to develop some key sensor or actuator, though some work will be needed here for the medium-term applications. It is our lack of experience of systems integration and systems engineering, and we need to build robust and cost-effective systems for the agricultural market.

We do not have currently an agricultural robotics industry. We have industries that are accustomed to working in harsh and unstructured environments: subsea, nuclear, defence. Perhaps there should be a greater transfer of technology into this area. Also we don't yet know enough about what the end user wants.

Long-term research has a lot in common with other advanced robotic applications, for example in walking robots. Medium term research needs to be directed to particular agricultural applications and there are many possible directions it could take. One area mentioned specifically by the report is manipulation of irregular soft materials. Others are decision support and decision systems, and sensor-based control. Here, particularly, vision guidance and vision-based control are particularly important.

In application development, where is niche commercial justification, the funding may be available, but in most other areas there may be somebody with the technology who is not able to develop it, a grower who cannot pay for it to be developed, and a machinery company that does not have the technology and may not be willing to take the risk. In such cases there is a need for those three to be working together, and the external funding to make the work possible. This was one of the key recommendations that were made to the Government.

In conclusion, Hopper recalled that there had been many promises in regard to automation and robotics over the years, which have not been fulfilled. However, there has been steady progress, and effective applications for agriculture can be produced today with significant development. The user community and machinery manufacturers are more aware, and there a new generation of engineers coming into industry and into the farms who are computer literate and would like to see this kind of development.

The UK is in the world premier league, though there are threats from, for example, Japan and The Netherlands, but we need to ensure that we do not simply have to buy robots from other countries. We must begin with some flagship applications that will need funding.

## Slug-powered robot

Dr Ian Kelly, of the Intelligent Autonomous Systems Engineering Laboratory at the University of the West of England, gave a lively account of development work on an autonomous robot for harvesting slugs (Figures 2–4). The need for such a device is becoming acute with the increasing demand for organically grown produce, which has not been sprayed with pesticides. In the UK alone £10m yearly is spent on chemical pesticides, and another £10m a year in spreading them. Another consequence of spraying pesticides is that they tend to kill off the natural predators, so increasing the need for chemical methods.

Most mobile robots are not truly autonomous: most of them operate in simplified environments; almost all non-industrial robots still require a helping hand from humans, such as battery changing, the odd push if they get stuck, and so on. The notable exceptions are smart missiles, satellites and torpedoes that

Figure 2 Slugbot robot has a 1.5m arm on a turntable to minimise travel



Figure 3 Gripper of Slugbot is designed as far as possible to prevent slime from adhering to the fingers

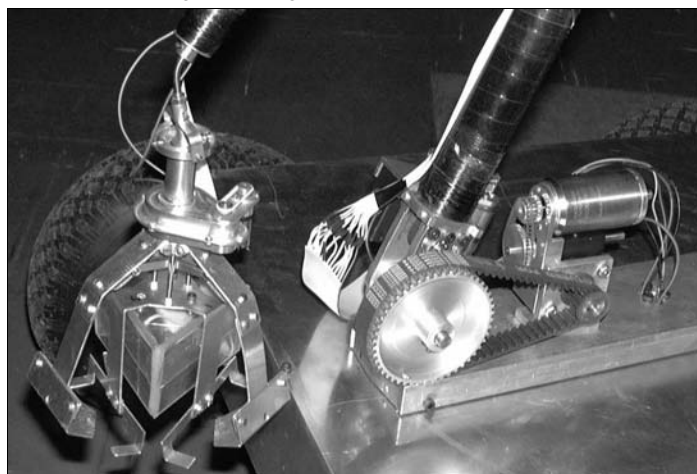
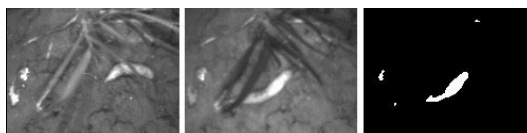


Figure 4 Images of a slug under different lighting conditions. Right-hand image is under red light



carry enough fuel and computational resources to complete their missions.

On the other hand, even the simplest animals are self-sufficient, in terms of both information processing and energy. The aim of Kelly's project was to build a robot with animal-like self-sufficiency in both information and energy. "We don't expect to be able to match the speed and performance of a cheetah chasing a zebra, within the time frame of this project, so we decided to chase something slightly slower – slugs. Apart from their relative ease of capture, slugs were chosen because they are a major pest, are reasonably plentiful, have no hard shell or skeleton, and are reasonably large."

To make the robot completely autonomous it will have to convert the slugs into a form of energy that is useful to a robotic system. The aim is to convert the organic material into electricity by first fermenting them to obtain methane gas, and then using the gas to power an engine driving a generator. Agricultural fields of winter wheat offer a suitable test bed for the robots, because slugs are plentiful, with up to 200 per square metre. They are most active, conveniently, when the crop is small enough to spring back after a robot has passed over it. Slugs are mainly active at night, especially just after sunset and just before sunrise, so the robots will have to be active at these times and resting during the day when most slugs are under ground.

The robot itself needs to be light, to conserve energy and also to avoid damaging the wheat, so the fermentation vessel, generator and engine need to be kept stationary where they may be served by more than one robot. In order to minimize movement the robot will be equipped with a 1.5m long arm, mounted on a turntable. Slugs are relatively difficult to see under daylight with the naked eye, but they can be detected relatively easily with a CMOS image sensor under red illumination. The robot needs to store the slugs, and must monitor the amount of power it has left, because it must not lose power on the way back to the fermentation station. Once there it will re-charge during the day, shutting down so it uses hardly any energy.

Considering mechanical design, Kelly said that a tracked vehicle was considered but rejected because of possible damage to crops when turning. Balloon tyres were eventually selected, with four-wheel drive. A simple vision system is adequate, and the best image is obtained under red light (on the right in

Figure 4). The robot will find its way back to the fermentation station using a differential global positioning satellite (DGPS) system, which gives accuracy to better than one metre but is still not good enough for docking, together with an active infra-red localization system.

The DGPS system also enables the robots to map out the territory to show where most slugs are to be found. It can also make sure that the robots do not all go to the same place. There also needs to be some method of detecting large obstacles, using a combination of ultrasonic sonar and bump sensors.

### Automated crop spraying

Lloyd also reported on behalf of a colleague, about the Nitrohawk automated crop-spraying helicopter. This is a small radio-controlled machine carrying sensors and a camera mounted on a pan and tilt platform. It can be used for a variety of purposes including land mine detection, but there is an agricultural application in crop spraying. It is carried, with the blades folded, in a box complete with the control system, and can be unpacked and flying within about two minutes. The Mark II version can carry a payload of up to 53½lb of chemical. The advantage is that it can fly over a field without in any way damaging the crop. It can also survey the field before spraying. Flight duration before refuelling is about 30 minutes, and it will fly at up to 156miles/h. The radio-controlled range is up to 1km.

### Harvesting and handling

John Reed, leader of the Robotics and Automation Group at Silsoe, underlined some of the challenges that make automation in agriculture and food different from manufacturing production. For a start, biological variations may include size, shape, colour, weight and texture. The objects handled are easily bruised, so need special handling equipment. Subjective decision making may be required, and the environment may be unstructured, especially if working out of doors.

"We think advanced engineering has a lot to offer," said Reed, and his broad definition included robotics, sensors, image analysis, information technology and control and intelligent automation. To these he added biomaterials, which involved understanding

the details of the object being handled. Embracing all of these, he suggested a new word – biomechatronics.

Robotic mushroom harvesting was chosen as a food handling exemplar, for several reasons. It has a national crop value of £300 million a year – the highest value horticultural crop grown in this country. It is labour intensive: 90 per cent of the crop is grown fresh for market and every mushroom is picked individually by hand, so there are more people picking mushrooms in horticulture than any other single job. It is cropped all year round, is very delicate, the supermarkets demand very high quality, and the environment is relatively structured, being indoors and dark.

It is necessary to take account of the physical properties of mushrooms. For commercial markets they need to be in the range 25-65mm. Shape, weight, inertia and centre of gravity are also important measurands. Mechanical stiffness, resistance to damage, torsion and bend characteristics and surface properties like coefficient of friction have a bearing on handling mushrooms, which are picked by a twist and bend technique. The mushrooms have a film on their surface which can contaminate and damage the end effector, so there must be a cleaning facility.

There are a number of generic tasks which mushroom harvesting shares with other applications, though not necessarily in the same order. These are: location; sizing; selection; pick-up; transfer; placement; processing (trimming in the case of mushrooms); conveying and packing.

The most popular method of growing mushrooms in the UK is on shelves, and trays are also used. Both these methods are also used in The Netherlands where they have started to use automatic tray systems, which stack the trays and deliver them by conveyor to the operator.

This is the approach used in the Silsoe conveyor-fed method of mushroom harvesting (Plate 1). A scanning vision system reliably detects the position and size of the mushrooms on their growing bed. The image is analysed using a specially written algorithm, which locates sizes and assigns a reference number to each mushroom. A second algorithm is then used to select the most appropriate picking order. By bending mushrooms into an available space they are detached by bending and twisting without disturbing previously touching neighbours. The end effector has a suction cup which

**Plate 1** Automatic harvesting robot detects suitable mushrooms, picks them by bend and twist, trims and delivers to packing



picks up the mushroom and transfers it to a finger conveyor which individually transfers the mushrooms to a special high-speed trimmer and thence to a gripper transfer station for packing.

### Automated sample analysis

Denys Dugendre, Automated Systems Consultant with Rhône-Poulenc Agriculture, told the meeting about some of the R&D work on herbicides going on at the company's Ongar, Essex, plant. The use of agrochemicals is increasingly heavily regulated, which means that large numbers of soil and plant samples have to be prepared. Competition is also a factor demanding speed of analysis, so there is an increasing need for automation of these repetitive processes.

When a new compound is used in field trials, soil and plant samples are collected for analysis. The same steps are taken whether the analysis is manual or automatic, but automation gives greater consistency of results. The succession of operations carried out on a given sample will depend not only on the result obtained from the previous operation but also on decisions taken by the analyst undertaking the experiment. Being a tool for method development and optimization, the system evolves gradually towards becoming an expert system. Ultimately the automated sample analysis system will be interfaced to a global Laboratory Information

Management System, along with the company's other laboratories.

The automated line has 21 workstations alongside a 6-metre track on which runs a 6-axis CRS A465 robot (Figure 5). The workstations include mixers, evaporators, extractions, centrifuge, LSC, balance and so on. An important restriction is that the robot gripper must hold the glass test tubes vertically at all times. The gripper has been designed to fit all the current workstations, but any future workstations will have to be designed around the gripper. The servo gripper incorporates a force sensor giving real-time feedback. It is designed to grip a wide range of glass vessels and calibration weights with an outside diameter in the range 11.5-65mm.

The control system incorporates five networked computers to distribute the workload of controlling 12 serial devices, including the PLC and the robot controller. The system software incorporates a graphical user interface, a reporting tool, and importing and exporting of data to and from the Laboratory Information Management System.

The company has just come to the end of a three-year teaching company scheme in association with Middlesex University, in which it recruited three engineers – mechanical, software and electronics – each for a two-year period, who carried out a simulation project to optimize the throughput of the line and the cell layout in the line. Optimization involved looking at the interlinked designs of the robot gripper, the workstations and the glassware.

Benefits expected from applications of the new system include increased throughput of samples, a shorter lead time in some cases

depending on the method being used, and a saving in personnel. Among more intangible benefits are that the line can be used as a method development tool; it gives improved consistency of analysis and data integrity; it allows better planning of work; and statistical information is always readily available.

More information can be obtained from the authors of the presentations:

- Dr Nick Tillett, Project Leader, Robotics and Automation Group, Bio Engineering Division, Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire MK45 4HS. Tel: +44 (0)1525 860000; Fax: +44 (0)1525 860156; E-mail: [nick.tillett@bbsrc.ac.uk](mailto:nick.tillett@bbsrc.ac.uk). There is a brief report on the computer-guided hoe and other activities of the Silsoe Research Institute on its Web site at <http://www.sri.bbsrc.ac.uk> The hoe is reported on the news pages at <http://www.sri.bbsrc.ac.uk/news/News4a.htm>
- Dr David Hopper, UK Robotics Ltd, The National Advanced Robotics Research Centre, Clarence Avenue, Trafford Park, Manchester M17 1QS. Tel: +44 (0)161 876 3212; Fax: +44 (0)161 876 3201; E-mail [David.Hopper@Robotics.co.uk](mailto:David.Hopper@Robotics.co.uk)
- Dr Ian Kelly, University of the West of England, Intelligent Autonomous Systems Group, Du Pont Building, Faculty of Engineering, Frenchay, Bristol BS16 1QY. Tel: +44 (0)117 965 6261 ~ 2870; Fax: +44 (0)117 976 2150. Dr Kelly has a page for Slugbot on the UWE Web site at <http://www.uwe.ac.uk/facults/eng/ias/iankelly/tta.htm>
- John Reed, Robotics and Automation Group, Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire MK45 4HS. Tel: +44 (0)1525 860000; Fax: +44 (0)1525 860156. There is a report on mushroom harvesting at <http://www.sri.bbsrc.ac.uk/SCIGRPS/sg4/mushroom.htm>
- Denys Dugendre, Automated System Consultant, Automation Group, Information Services, Rhône-Poulenc Agriculture Ltd, Fyfield Road, Ongar, Essex CM5 0HW. Tel: +44 (0)1277 30 1428; Fax: +44 (0)1277 30 1189; E-mail: [denys.dugendre@rhone-poulenc.com](mailto:denys.dugendre@rhone-poulenc.com)
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**Figure 5** Automated sample analysis line at Rhône-Poulenc Agriculture has 21 workstations and a 6-axis CRS robot

