ROBOTIC AGRICULTURE –
THE FUTURE OF AGRICULTURAL MECHANISATION?

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Robotic agriculture – the future of agricultural mechanisation?

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Abstract

Developed agriculture needs to find new ways to improve efficiency. One approach is to utilise available information technologies in the form of more intelligent machines to reduce and target energy inputs in more effective ways than in the past. Precision Farming has shown benefits of this approach but we can now move towards a new generation of equipment. The advent of autonomous system architectures gives us the opportunity to develop a complete new range of agricultural equipment based on small smart machines that can do the right thing, in the right place, at the right time in the right way.

Keywords: robots, autonomous, mechanisation, robotic weeding, Phytotechnology.

Introduction

The idea of robotic agriculture (agricultural environments serviced by smart machines) is not a new one. Many engineers have developed driverless tractors in the past but they have not been successful as they did not have the ability to embrace the complexity of the real world. Most of them assumed an industrial style of farming where everything was known before hand and the machines could work entirely in predefined ways – much like a production line. The approach is now to develop smarter machines that are intelligent enough to work in an unmodified or semi natural environment. These machines do not have to be intelligent in the way we see people as intelligent but must exhibit sensible behaviour in recognised contexts. In this way they should have enough intelligence embedded within them to behave sensibly for long periods of time, unattended, in a semi-natural environment, whilst carrying out a useful task. One way of understanding the complexity has been to identify what people do in certain situations and decompose the actions into machine control. This is called behavioural robotics and a draft method for applying this approach to agriculture is given in Blackmore *et. al.* (2004b).

The approach of treating crop and soil selectively according to their needs by small autonomous machines is the natural next step in the development of Precision Farming (PF) as it reduces the field scale right down to the individual plant or Phytotechnology (Shibusawa 1996). One simple definition of PF is doing the right thing in the right place at the right time with the right amount. This definition not only applies to robotic agriculture (RA) and Phytotechnology but it also implies a level of automation inherent in the machines. Automatic sensing and control (on-the-go) for each task is also important and many research papers have shown that these systems are feasible but most are too slow, and hence not economically viable, to be operated on a manned tractor.

Once these systems are mounted on an autonomous vehicle, they may well suddenly become commercially viable.

By taking a systems approach, in which we consider a system in terms of its actions, interactions and implications, we can develop a new mechanization system that collectively deals with all the crop's agronomic needs in a better way. To do this we must stop defining plant care in terms of the current mechanisation but in terms of what the plant needs. When we have defined the actual plant requirements we are then free to design a better way of dealing with them.

The environmental implications would seem good. Minimised inputs to reduce waste and pollution, controlled biodiversity by retaining non-competitive weeds, more intelligent physical methods replacing chemical solutions are all examples of how Phytotechnology could benefit the environment over traditional methods. Economic factors include lower labour costs (a significant saving if they can be made fully autonomous), incremental investment in, perhaps, a small machine each year, rather than a single large machine every 5 years. These small vehicles could be assembled from existing mass produced components such as car parts without the need for specialised design and tooling. Consideration of social aspects shows that the public are ready for small intelligent machines to be used in food production, by the level of interest shown by the media and when being demonstrated. Insurance and liability will be a lot easier with smaller autonomous machines.

Modern agriculture uses a lot of energy. It comes in many forms from fertilisers and chemicals to tractors and fuel. The Phytotechnology approach tries to target the introduced energy to improve efficacy. Chamen (1994) identified that a 70% energy saving can be made in cultivation energy by moving from traditional trafficked systems (255 MJ/ha) to a non-trafficked system (79 MJ/ha). This was for shallow ploughing and did not include any deep loosening. From this we estimate that 80-90% of the energy going into traditional cultivation is there to repair the damage done by large tractors. It would be much better to not cause compaction in the first place which is one of the reasons that leads us to consider using small light machines.

Most of the current machinery is very weather dependant. Tractors cannot drive on soil when it is wet, sprayers cannot work in high winds etc. Perhaps it will be possible to develop smaller, less intrusive machinery that can allow more tasks to be carried out in marginal conditions. An example might be an autonomous seeder that could function well, while the soil is still wet in the springtime, provided that the soil engagement mechanism is suitable arranged. This would allow the seeds to be planted when optimal for the crop and not be limited by the soil's ability to support the tractor.

Safety is another important factor. Any autonomous vehicle is going to go wrong at some time and the chance of catastrophic failure should be minimised within the design process. A small light vehicle is inherently safer than a large one. Redundant, self-checking systems should be built into the system architecture to allow graceful degradation. The vehicle should be in continual communication with the base station, giving data about current conditions and contexts. Many of the design parameters are discussed in (Blackmore et al. 2004a)

This approach may not be economically justifiable in many broad acre crops but will certainly be more attractive in high value crops where a smart machine can replace expensive repetitive labour. If this approach were taken, it would appear that the crop production cycle could be reduced to three stages: Seeding, Plant care and (selective) harvesting.

Establishment

Seed bed preparation

Ploughing is one of the most important primary cultivation processes and has been carried out since the start of civilization. It is effectively the inversion or mixing of topsoil to prepare a suitable seed bed. It also has the ability to bury surface crop residues and control weeds. A small robot utilising current technology does not have the energy density to sustain ploughing over a large area due to the high levels of energy needed to cut and invert the dense soil. Secondly, the draft force required to plough also needs relatively high weight to give traction. Perhaps we would leave it at that, but by considering what the plant, or in this case the seed actually needs, we can approach the problem in a different way. The seed requires contact with the soil moisture to allow uptake of water and nutrients, it requires stability to hold the growing plant and a structure that allows the roots to develop and the shoots to grow. A solution is two fold. Firstly if we do not compact the soil in the first place there is less need for energy inputs for remedial loosening. Natural soil flora and fauna can be encouraged to manipulate the soil to give a good structure. This is one of the reasons to opt for smaller machines. Secondly, if the majority of the soil rooting depth is acceptable, then only the local environment of the seed needs to be conditioned before seed placement, which will take a lot less power. Add to this the ability to place nutrients in the correct proximity to the seed we can improve the early phase of establishment. This system has many of the advantages of direct drilling but incorporation of previous crop residues may still cause a problem although removal of crop residues is an option.

Seed mapping

Seed mapping is the concept of passively recording the geospatial position of each seed as it goes into the ground. It is relatively simple in practice as an RTK GPS is fitted to the seeder and infra red sensors mounted below the seed chute. As the seed drops, it cuts the infrared beam and triggers a data logger that records the position and orientation of the seeder. A simple kinematic model can then calculate the actual seed position (Griepentrog et al. 2003). The seed coordinates can then be used to target subsequent plant based operations.

Seed placement

Rather than just record the position of each seed it would be better to be able to control the seed position. This would allow not only allow the spatial variance of seed density to be changed but also have the ability to alter the seeding pattern. Most seeds are dropped at high densities within each row, whilst having relatively more space between the rows. From first agronomic principles, each plant should have equal access to spatial resources of air, light, ground moisture, etc. Perhaps a hexagonal or triangular seeding pattern might be more efficient in this context. If suitable controls are fitted to allow synchronisation between passes, then there is the possibility to plant seeds on a regular grid that can allow orthogonal inter-row weeding. Tests of such a machine will be carried out at KVL in 2005. (See also robotic weeding)

Reseeding

Reseeding is the concept of being able to identify where a seed was not planted, or that a crop plant has not emerged and a machine can automatically place another seed in the same position. This concept could be extended to transplanting a seedling instead of a seed if the surrounding plants are too far advanced. A reseeder would have the ability to insert individual seeds/plants without disturbing the surrounding crop. Conventional seeders could not then be used as they create continuous slots in the soil. A punch planter could be developed to fulfil this role, or better still adapt a Japanese transplanter to deal with one seedling at a time. Prior local micro-cultivation could be achieved by using a targeted water jet (or gel) to pierce the soil and soften it ready for the seedling roots. Figure 1, show a transplanter adapted to take a seeding mat. The seeding mat can also include crop nutrients. If this concept became efficient enough, it could also become the main seeder as well.

Figure 1. (Left) Japanese transplanter adapted to take a seed mat,
(Centre) Seed mat with rice seeds and fertiliser embedded in card
(Right) Rice seedlings ready for transplanting

Crop care

Crop scouting

One of the main operations within good management is the ability to collect timely and accurate information. Quantified data has tended to be expensive and sampling costs can quickly out weigh the benefits of spatially variable management. (Godwin et al. 2001) Data collection would be less expensive and timelier if an automated system could remain in the crop carrying a range of sensors to assess crop health and status. A high clearance platform is needed to carry instruments above the crop canopy and utilise GPS. Smaller sub canopy machines have been developed in student competitions. Examples of both types of machines are shown in Figure 2.

Figure 2. (Left) Portal crop scouting platform (Madsen and Jakobsen 2001),
(Right) Sub canopy robot ISAAC2 built by a student team from Hohenheim University (www.fieldrobot.nl)

The portal robot shown in Figure 2, has been extensively modified and rebuilt and has been used to provide automated crop surveys (Bak and Jakobsen, 2003). A range of sensors have been fitted to measure crop nutrient status and stress (multi spectral response), visible images (pan chromatic), weed species and weed density.

Weed mapping

Weed mapping is process of recording the position and preferably the density (biomass) of different weed species using aspects of machine vision. One method is to just record the increased leaf area found in weedy areas as weeds are patchy and the crops are planted in rows (Pedersen 2001). Another more accurate method is to use active shape recognition, originally developed to recognise human faces, to classify weed species by the shape of their outline (Søgaard and Heisel 2002). Current research has shown that up to 19 species can be recognised in this way. Colour segmentation has also shown to be useful in weed recognition (Tang et al. 2000). The final result is a weed map that can be further interpreted into a treatment map.

Robotic weeding

Knowing the position and severity of the weeds there are many methods that can kill, remove or retard these unwanted plants (Nørremark and Griepentrog 2004) Different physical methods can be used that rely on physical interaction with the weeds. A classic example is to break the soil and root interface by tillage and promote wilting of the weed plants. This can be achieved in the inter row area easily by using classical spring or duck foot tines. Intra row weeding is more difficult as it requires the position of the crop plant to be known so that the end effector can be steered away. Within the close-to-crop area, tillage cannot be used as any disturbance to the soil is likely to damage the interface between the crop and the soil. Non contact methods are being developed such as laser treatments (Heisel 2001) and micro-spraying.

Controlled biodiversity is an opportunity that could be realised with robotic weeding. Non-competitive weeds can be left to grow when they are at a distance from the crop. This is part of the design parameters for the Autonomous Christmas Tree weeder being developed at KVL. (See Figure 3)

Figure 3. (Left) The autonomous Christmas tree weeder,
(Right) Young Christmas trees with patchy weeds.

<u>Micro spraying</u>

Within the close-to-crop area, great care must be taken not to damage the crop nor disturb the soil. One method of killing weeds close to the crop plants is to use a micro spray that delivers very small amounts directly on to the weed leaf. Machine vision can be used to identify the position of an individual weed plant and a set of nozzles mounted close together can squirt a herbicide on to the weed. Tests have shown that splashing can be reduced when a gel is used as a carrier rather than water (Lund and Søgaard 2005).

Other trials have shown that when the right amount of herbicide is placed in the right way at the right time, the usage of herbicide can be drastically reduced to about 1 gram per hectare for an infestation of 100 weeds per square meter (Graglia 2004).

A micro spray system is currently under development at DIAS Bygholm, in Denmark.

<u>Robotic gantry</u>

Traditional or macro spraying can be very efficient, especially when they cover large areas. Most equipment manufacturers are developing larger machines, with 42 meter booms currently under development (*pers. com.* Hardi International). When mounting booms this big, they have inherent stability problems as the tractor has a relatively small wheelbase and they tend to oscillate. One method to improve stability would be to mount a spray boom between two unmanned robots that travelled in adjacent tramlines. This robotic gantry could apply both liquid sprays and fertiliser and be able to regulate itself according to current weather conditions. If it became too windy then the gantry could just stop and wait until conditions improved. Variable rate, patch spraying, minimising skips and overlaps could all be built into the original design specifications by controlling individual nozzles. Turning on the headland would be different, as it would not include rotation – just translation, as the robots could turn but the boom remains parallel to its working direction. Sensing systems could be mounted on a trolley that could move along the spray boom as in the crop scouting section.

<u>Robotic irrigation</u>

A robotic irrigator in the form of a mechatronic sprinkler (to simulate a travelling rain gun) was developed to apply variable rates of water and chemigation to predefined areas. The trajectory and sector angles of the jet were controlled by stepper motors and could be adjusted according the current weather and the desired pattern by a small computer.

When the airborne water was blown down wind, the jet angles could be adjusted to compensate by measuring the instantaneous wind speed and direction (Turker et al. 1998). This system could not only apply the required water in the right place but could irrigate into field corners.

Selective harvesting

Selective harvesting involves the concept of only harvesting those parts of the crop that meet certain quality thresholds. It can be considered to be a type of pre sorting based on sensory perception. Examples are to only harvest barley below a fixed protein content or combine grain that is dry enough (and leave the rest to dry out) or to select and harvest fruits and vegetables that meet a size criteria. As these criteria often attract quality premiums, increased economic returns could justify the additional sensing.

To be able to carry out selective harvesting effectively, two criteria are needed; the ability to sense the quality factor before harvest and the ability to harvest the product of interest without damaging the remaining crop. Most agricultural equipment is getting bigger and hence not suited for this approach. Smaller more versatile selective harvesting equipment is needed. Either the crop can be surveyed before harvest so that the information needed about where the crop of interest is located, or that the harvester may have sensors mounted that can ascertain the crop condition. The selective harvester can then harvest that crop that is ready, while leaving the rest to mature, dry, or ripen etc.

Alternatively, small autonomous whole crop harvesters could be used to selectively gather the entire crop from a selected area and transport it to a stationary processing system that could clean, sort and maybe pack the produce. This is not a new idea, but updating a system that used stationary threshing machines from many years ago. Alternatively a stripper header could be used to only gather the cereal heads and send them for threshing.

Conclusions

This paper has set out a vision of how aspects of crop production could be automated in the future. Although existing manned operations can be efficient over large areas there is a potential for reducing the scale of treatments with autonomous machines that may result in even higher efficiencies. The development process may be incremental but the overall concept requires a paradigm shift in the way we think about mechanisation for crop production that is based more on plant needs and novel ways of meeting them rather than modifying existing techniques.

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