Agricultural Robots – Applications and Economic Perspectives

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1. Introduction

1.1 General aspects

For many years robotic systems have been widely used for industrial production and in warehouses, where a controlled environment can be guaranteed. In agriculture and forestry, research into driverless vehicles has been a vision initiated in the early 1960's with basic research on projects on automatic steered systems and autonomous tractors (Wilson, 2000).

Recently, the development of robotic systems in agriculture has experienced an increased interest, which has led many experts to explore the possibilities to develop more rational and adaptable vehicles based on a behavioural approach. A combined application of new sensor systems, communication technologies, positioning systems (GPS) and geographical information systems (GIS) have enabled researchers to develop new autonomous vehicles for high value crops in the agriculture and horticulture soctor, as well as for landscape management.

Several autonomous prototypes have been described for orchards and horticultural crops, such as oranges (Hannan and Burks, 2004), strawberries (Kondo et al., 2005) and tomatoes (Chi & Ling, 2004). Moreover, automated systems for site specific irrigation based on real time climatic conditions have been described for high value crops (e.g. Miranda et al, 2005)

For field crops there are also a number of systems, such as the Demeter system for automated harvesting equipped with a camera and GPS for navigation (Pilarski et al., 2002), and the autonomous Christmas tree weeder (Have et al., 2005) and the API platform for patch spraying (Bak & Jacobsen, 2004). In addition we have seen automated systems for animal production in indoor environments such as automated feeding and cleaning.

In the open and outdoor environment, which will be the focus here, robotic and autonomous systems are more complex to develop - mainly because of safety issues. The robots safety system would have to be reliable enough for it to operate autonomously and unattended. It is relatively costly to develop safety systems if the vehicle has to be completely autonomous. In principle, they can work 24 hours a day but if a robot has to be attended then the time is limited by the person. In this matter different scenarios and degrees for autonomy have been investigated depending on the task to be carried out. Concepts have been initiated to investigate if small autonomous machines would be more efficient to replace the traditional large tractors. These vehicles should be able to carry out useful tasks all year round, unattended and able to behave sensibly in a semi-natural environment over long periods of time. The small vehicles may also have less environmental impact replacing the over-application of chemicals and fertilizers, requiring lower usage of energy with better control matched to requirements, as well as causing less soil compaction due to lighter weight.

Fig 1. MF-Scamp robots for scouting, weeding and harvesting (Designed by Blackmore. Copyright©2008 AGCO Ltd)

1.2 Economics

So far, only a few studies have been published on the economic consequences by introducing autonomous field machinery to achieve more sustainable production systems. Goense (2003) compared autonomous with conventional vehicles, equipped with implements having working widths from 50 to 120 cm. He showed that if an autonomous vehicles can be utilised 23 hours a day, it would be economic feasible with slight reductions in prices of navigation systems or with slight increases in labour costs. Goense also discussed a number of other changes that will affect the final result, such as the fraction of labour time needed out of the total machine time and the machine tracking system, which provides better utilisation of machine working width and there is no need for operators rest allowance. On the other hand, there may be negative effects in the form of higher costs in travelling distances for service personal.
Additionally, Have (2004) analysed the effects of automation on machinery sizes and costs for soil tillage and crop establishment. He assumed that the ratios between an autonomous tractor and a manned tractor, in terms of price, labour requirement and daily working hours would be 1.2, 0.2, and 2 times, respectively. The analysis, which included all direct machinery and timeliness costs showed that the shift to automatic control would decrease the tractor size, implement sizes and implement investments to about half; decrease the tractor investment to about 60% and decrease the sum of annual tractor and machinery costs to approximately 65%. Pedersen et. al. (2006 & 2007) outlined a comparison between 3 different applications of robot systems with conventional systems for crop production and landscape treatment. The economic feasibility study in thepresent chapter relies on some of these scenarios and descriptions.

1.3 Objectives

The aim of this chapter is to present the status of the current trends and implementation of agricultural and horticultural robots and autonomous systems and outline the potential for future applications. Different applications of autonomous vehicles in agriculture have been examined and compared with conventional systems, where three main groups of field operations have been identified to be the first potential practical applications: crop establishment, plant care and selective harvesting.

Moreover we will give examples of the economic potential of applying autonomous robotic vehicles compared to conventional systems in two different applications: robotic weeding in high value crops, particularly sugar beet, and crop scouting in cereals. The comparison was based on a systems analysis and an individual economic feasibility study for each of the applications. Focus will be put on potential labour cost savings, farm structure implications and sizes for operation, daily working hours, potential environmental impact, energy costs and safety issues.

2. Autonomous vehicles scenarios

2.1 Crop establishment

Several concepts of crop production and cultivation are now being revisited and reconsidered in the light of developing smarter machines.

For traditional crop establishment and seed bed preparation it has been common that the whole topsoil of a field is inverted with a plough to create a suitable seed bed. This is a well known operation that suits many circumstances but it also uses a lot of energy. If this approach is turned around to consider the actual seed requirements, other methods with reduced tillage may become an option. The seed requires contact with soil moisture to allow uptake of water and nutrients; it requires a structure that can hold the plant upright but also allow the roots to develop and the shoots to grow. Moreover it requires space with little competition from other plant seeds. If the same seed environment can be achieved by only mixing the soil within a few centimetres of the actual seed then the rest of the soil does not need to be disturbed as it can be well conditioned by natural soil flora and fauna.

Another traditional concept is to grow crops in rows. It would seem that the only explanation as to why this is done is that it requires the simplest type of machines. Seeds are placed relatively densely along each row. The problem is that in principle, each plant requires equal access to light, air, water and nutrients, which are often spatially related. Intra crop competition can be reduced by giving a more even or equal spacing and seed distribution with accurate placement of seeds in a more uniform pattern (see figure 2).

In figure 2 the main crop is illustrated with green spots and the weeds are red spots. On the left of figure 2 the crop is seeded in traditional rows. Here, it is possible for the weed to grow fast and overtake the main crop at an early development stage. On the right side the crop is distributed uniformly with seed placement. In principle, the main crop will cover the weed before the weed develops and thereby reduce the weed pressure. Initial trials indicate that it may be possible to reduce the weed biomass with up to 60% by using uniform patterns with accurate seed placement (Weiner and Olsen 2007).

If the location of each seed is known and the position of each emerged crop plant is estimated, it will be possible to identify each plant by its spatial location. Improved information about plant characteristics allows improved management and decision making and allows a number of improved, more targeted operations that can improve the overall crop growing efficiency. As only a small volume of soil is needed to be cultivated there are a number of different methods that could be used. Rotary mechanical tillage in two dimensions on a vertical or horizontal axis (as indicated in the seed map in Figure 2) could be used instead of just one dimension or water-jetting or the injection of a hygroscopic polymer gel could be used to create a micro climate for the seed.

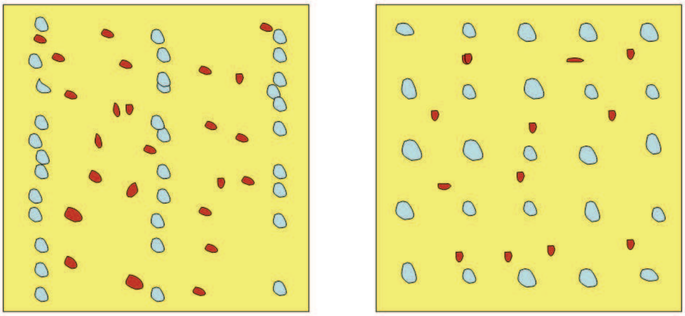

Fig. 2 Precise seed placement in uniform patterns (Source. Based on Weiner J and Olsen J, 2007. Momentum 2007)

Seed mapping is relatively simple in practice as a tilt adjusted RTK-GPS could be fitted to the high precision 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 indicated position and orientation of the seeder. A simple kinematic model can then calculate the actual seed position (Griepentrog et al., 2005a). However, ultra high precision placement of seed is difficult from a moving machine. Even the most sophisticated commercial machines have problems with consistently separating individual seeds and will often damage the seeds as they pass through the metering mechanisms. Some mechanisms do ensure that each seed has zero ground velocity which is important to stop the seed bouncing after impact with the soil (Griepentrog et al., 2005b).

2.2 Crop scouting

An important part of good management is the ability to collect timely and accurate information about the crop development. Quantified data has tended to be expensive and sampling costs can quickly out weigh the benefits of spatially variable management. (Godwin et al., 2003).

Data collection would be less expensive and timelier if an automated system could remain within the crop canopy for continual monitoring that can be used for assessing crop status. This could be achieved by either embedding cheap wireless sensors at strategic positions within the crop, or placing more expensive sensors onto a moving platform.

Crop characteristics would include Leaf Area Index, crop height (giving growth rates), growth stage, biomass, senescence, etc. Crop nutrient status is difficult to assess in the early stages and assessing it independently from moisture stress become very complex (Christensen et al., 2005).

With the advent of biosensors, a whole new set of opportunities will become available to monitor growing crops for pest and disease attack (Tothill, 2001). As the robotic/autonomous vehicle could patrol the fields continually looking for weeds and other threats, real-time alerts could be sent to the manager whenever certain conditions were encountered. These could take the form of noting actual pest or disease attack or by monitoring environmental conditions where they are likely to occur or that the risk of attack is significant. Differing growth rates could also be used to identify potential problems.

2.3 Selective harvesting

At present, crops are usually harvested when the average of the whole field is ready as this simplifies the harvest process. Selective harvesting involves the concept of only harvesting those parts of the crop that meet certain quantity or quality thresholds. It can be considered to be a type of pre sorting based on sensory perception. Selective harvesting has been well known in forestry for many years where certain trees are harvested according to quality and size or to improve the quality of the remaining trees.

In agriculture, examples could be 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. Benefits of multiple-pass system than a single-pass for corn harvested for biomass has been reported by Shineers et al. (2003), as well as the advantages for selective harvesting of asparagus (Cembali et al., 2005) and dates in Iran (Abounajmi, 2004). To be able to carry out selective harvesting effectively, two criteria have to be met; 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 vehicles are getting bigger and hence not suited for this approach. Therefore, smaller and more versatile selective harvesting equipment is needed for this purpose. 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. As selective harvesting only harvests products of desired quality the harvesting process will be phased over a longer periods of time, negating the need for large equipment. As the products are already graded or sorted, it also adds value to the products before they leave the farm.

3. Economic scenarios

In this section, we have compared the costs and benefits of the potential commercial use of robotic vehicles. We based the calculations on partial budgeting, where the cost change is compared to conventional practices. In this model, we included changes in initial investments, labour costs, change in speed, daily working hours, energy consumption, control and surveillance costs. We compared the saved labour and spraying costs and additional costs for electronic devices, GPS-system and platforms for the robotic systems with conventional manned systems.

Technical parameters such as dimensions, capacities, speed and related costs were based on recommendations from other research groups and experts. However the economic figures such as period of depreciation, real interest rate (5 %) and maintenance costs were based on the authors' assumptions.

For the two scenarios: **field scouting for weed detection** and **weeding**, the model was built to project potential applications in conventional farms with average field size and crop rotations. These two application technologies are fairly mature currently at a pre-commercial development stage.

The data for the conventional applications, were taken from general economic statistics for the Danish farm management standards, regarding specific costs for contracting. Moreover, we have received data from researchers at Danish Institute of Agricultural Sciences (DIAS), Bygholm, that are working with these specific applications on an autonomous platform. The autonomous platform that they are using is the Autonomous Plant Inspection (API) research platform (Bak and Jakobsen, 2004).

We assumed that the period of depreciation is 10 years with linear depreciation. The real interest rate was 5% and we assumed that it would be necessary to add some additional labour time (two weeks) for testing and making the necessary calibrations for the systems.

3.1 Field scouting for weed detection

Weed mapping is the process of recording the position, density (biomass) and preferably species of different weeds using machine vision. For automatic weed detection, several studies have been performed applying different discrimination and classification techniques. Manh et al. (2001) used parametric deformable templates to segment individual weed leaves, Sokefeld et al. (2000) identified more than 20 weed species using Fourier descriptors and shape parameters, while Sogaard (2005) used Active Shape Models to identify 19 weed species. Artificial neural networks have also been used by many researchers to discriminate weeds (e.g. Burks et al., 2005; Granito et al., 2005) with machine vision. Other researchers have used image analysis techniques for weed discrimination using remote sensing from ground sensors (e.g. Vrindts et al., 2002) and airborne photography (e.g. Godwin and Miller, 2003).

Weed mapping is a hypothetical scenario in the sense that most farmers do not conduct systematic field scouting in their cereal fields today. Farmers either practice conventional farming with conventional spraying or they conduct organic farming with mechanical weeding. In this comparison, we assume that the alternative to autonomous weed mapping is manual weed mapping, which implies that the farmer has to register and map the weeds in the field manually with a handheld GPS.

In the weed mapping scenario, we compared autonomous field scouting for weeds in cereals with the manual detection of weeds. The autonomous system requires an API vehicle and cameras for weed detection and mapping. The Danish Institute of Agricultural Sciences (DIAS) has performed tests using such a vehicle for weed recognition and data from personal communications with the researchers have been used for our calculations. The API platform, (Fig.2) was initially developed by Madsen and Jakobsen (2001). Now, there is the third generation of API vehicle, further developed by Aalborg University in Denmark. This prototype has four wheel-drive, four-wheel steering with two motors per wheel, one providing propulsion and the other steering to achieve higher mobility (Bisgaard et al., 2004).

The platform has a height clearance of 60 cm and track width of 1 m. It is equipped with an Real Time Kinematic Global Positioning System (RTK-GPS) and on the top of the frame there is an operating console and an implement for the agricultural operation such as spraying devices, sensors or weeding tools. The vehicle communicates with the farm management PC for navigation, according to the computed route plan, as well as collision avoidance (Bak and Jakobsen, 2004). Based on shape recognition of weeds it is possible to create a weed map of the entire field.

Fig. 3. The API platform.

In this scenario, the area for field scouting and weed mapping is limited to 500 ha to match large production units with the necessary flexibility. We have focused on cereal crops but it may also be relevant for other crops such as high value crops like sugar beet, potatoes or other horticultural crops. However, the shorter the time for carrying out the activity, the lower the overall capacity required.

In weed mapping/field scouting, the robotic system is compared with manual detection of weeds. Most of the time for manual weed scouting will take place in the first year, which is followed by shorter update scouting in the following years. Manual weed scouting is assumed to require about 0.7 man h/yr/ha (Pedersen, 2003). The weed patches are registered by using GPS and GIS systems to create weed maps of the individual fields. Autonomous field scouting using the API platform has a speed of 3.6 km/h and a capacity of 4.32 ha/h, which adds up to 116 h/y for autonomous weed scouting on a 500 ha area giving 0.232 h/yr/ha.

An automated weed mapping system will enable the farmer to produce weed maps, which will be useful to carry out precise patch spraying with the right mixture and dose rates of herbicides where it is needed. The technology and decision support systems to apply patch spraying is available and herbicide savings can vary from 30% and up to 75% (Heisel et al., 1999; Sogaard, 2005).

The autonomous field scouting system in cereals reduces the costs by about 20 % compared to manual weed scouting but it should be possible to increase the capacity to 1000-2000 ha since the system, as presented here, is only used 116 h/y (Pedersen et. al 2006)

Since the costs of the autonomous platform is based on estimated costs of producing the platform it might be the case that a commercial selling price will be significantly higher. An 100 % increase of the cost of the API-platform to 30,300 € will imply that the overall costs of the autonomous field scouting system will increase to 20.3 €/ha/year, which is slightly above the labour costs for manual weed scouting.

3.2 Weeding

3.2.1 Weeding methods

As outlined above it could be possible to automate weed mapping by using active shape models and GPS systems in cereals. However, one issue is to collect data about weeds; another issue is to physically remove the weeds.

There are several methods that can remove or kill unwanted plants without using chemicals (Nørremark and Griepentrog, 2004). These can range from total removal down to simple retardation. A classic example would be to promote the wilting of the weed plants by breaking the soil and root interface by tilling the soil within the root zone.

In principle, there are three main areas within the crop environment that require different types of treatment: The inter-row area (the space between the crop rows), the intra-row area (the space between the plants within the row), and the close-to-crop area that is within the leaf and root envelope. The closer to the crop that a machine should operate, increased care and accuracy is needed so as not to damage the crop plant tissue.

The inter-row area is relatively easy to keep free of weeds as it is an open strip in line with the direction of travel. The intra-row area is more difficult to manage as it is an intermittent space delineated by irregular spacing of crop plants. The close-to-crop area should not have any soil disturbance as this would lead to possible wilting. Weeds within this area are likely to incur the most competition of all as they are so close to the crop plant's resources. Retardation of weeds in this area must rely on intelligent sensing and highly targeted energy inputs such as micro spraying or laser weeding.

Laser weeding holds great promise as it uses a highly mobile focused beam of infra red light to thermally disrupt cell membranes in the weed leaves and shoots. The beam can be controlled easily by computer and can significantly reduce the energy needed for thermal weed control (Griepentrog et al., 2006). Location of weed leaves can be achieved by machine vision (as above)

3.2.2 Micro spraying

Micro spraying takes the concept of a spray boom down to the centimetre level (Søgaard et al., 2006). It applies highly targeted chemicals and can treat small areas by selectively switching the jets on and off. It is part of a larger system that can recognise individual weed plants and locate their leaves for treatment (see weed mapping).

Trials have shown that when herbicide is targeted in the right way at the right time, the usage can be drastically reduced. Tests were carried out by a human operator to identify and treat individual weed plants that resulted in reducing the application of glyphosphate from 720 grams per hectare down to about 1 gram per hectare for an infestation of 100 weeds per square meter and maintain acceptable efficacy (Graglia, 2004). If this same approach can be carried out by an autonomous micro sprayer then there will be significant economic and environmental advantages.

Within the close-to-crop area, great care must be taken not to damage the crop nor disturb the soil. The use of a micro spray that delivers very small amounts directly on to the weed leaf has been fitted to the crop scouting robot described above. 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 (Søgaard & Lund, 2005).

3.2.3 Robotic weeding

The financial analysis here focuses on the potential application of micro spraying in sugar beets in four regions that differ in terms of farm structure, farm sizes and land topography, namely, Denmark, Greece, UK and USA (Red River Valley). Sugar production in the four regions are: Denmark (48700 ha), Greece (35973 ha), US (528890 ha) and UK (154000 ha). FAO statistics 2004.

We have focused on four case areas that all produce sugar beet but differs in terms of labour cost and average farm sizes – with the highest in the US. However, in the US, most crops are produced less intensively with less input factors. Sugar beet production occurs in 12 US states and about 48% of the US sugar beet acreage is located in the Red River Valley (Minnesota and Eastern North Dakota). The average US sugar beet farm area is about 80 ha (Ali 2004) and the average field size for sugar beet is 6.5 ha in UK although some fields may be as large as 40-50 ha. Currently in the UK, there are a little under 9,000 growers and about 150,000-180,000 ha of sugar beet is grown annually.

In the ***robotic weeding*** scenario, we compared an autonomous vehicle equipped with a micro spraying system with a conventional sprayer for sugar beet. The micro spraying system would be mounted on an API platform as illustrated in figure 3.

The micro sprayer consists of a set of eight micro valves with a driver circuit for each nozzle. It is assumed that this system can reduce the application of herbicides by 90% compared with standard doses in sugar beet (Lund and Sogaard, 2004). The working speed is 1.8 km/h with recharging of batteries every 5 h. The vehicle has a width of 2 m with a capacity to treat 4 rows simultaneously.

Inter-row weeding (between the rows) is envisaged to be carried out conventionally. We only focus on the intra-row weeding close to the crop. The season for operation is limited from April to July. The robotic weeding is compared with the costs of conventional weeding in sugar beet. The costs for these operations are based on average prices for contracting. The API platform, as designed for this scenario, is equipped with 4 micro spraying systems. The autonomous platform is able to cover 4 rows at a time. The speed is 1.8 km/h and the capacity is 0.4 ha/h, which adds up to between 417 h/y in Greece and 883 h/y in UK and US for autonomous weeding. For the autonomous micro spray system, inter-row hoeing has to be conducted twice whereas, for conventional spraying, we assume one treatment. For comparison, it might be relevant to inter-row hoe 3 times when conducting band spraying.

Based on the assumptions above, the potential economic viability of operating this system compared to a similar treatment with conventional practices were determined. The total investments for the systems are indicated as depreciation and capital costs.

The RTK-GPS system is still fairly expensive for these practices although the price is expected to be reduced as the technology becomes more widespread. The cost of receiving a GPS reference signal accounts for a significant share of the yearly costs for both systems. For both systems, we assume a depreciation period of 10 years. Maintenance of investments was assumed to be an additional 3 %.

For weeding in sugar beet, the primary savings were related to the reduced application of herbicides and additional costs were related to investments in micro-sprayers. A comparison between the costs in Red River Valley and Denmark indicated that the pesticide costs on conventional average farms are about 200-220 € in both regions.

	Robotic weeding in sugar beet			
	DK	GR	US*	UK
Platform with RTK-GPS	API system	API system	API system	API system
Total area treated with autonomous system , ha	80	50	100	100
Operation time per day, h/day	16	12	16	16
Operation hours, h/yr	667	417	883	883
Days for operation, days	42	35	52	52
Wages, unskilled labour, €/hour	14	6	9	10
Electricity costs 100kwh, in €	9.30	6.68	8.18	9.05

Table 1. Technical and financial assumptions for the system analysis
Source: Pedersen et al 2007.
* Red River Valley (Minnesota and Eastern North Dakota)
Exchange rates: 1 € = 7.45 DKK, 0,68£, 1,34 $

With the autonomous system, it is possible to handle 4 rows with the API platform and possible more (6-10 rows) in the future. Moreover, the costs of each spraying system are likely to be reduced with larger systems.

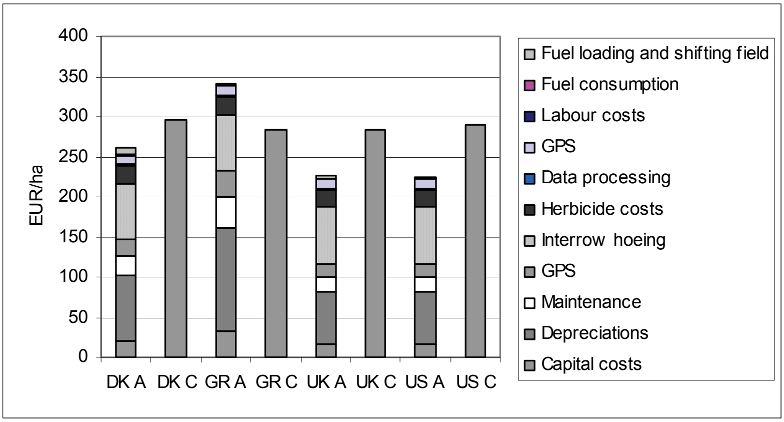

Fig. 4. Cost structure for autonomous (A) and conventional (C) weeding in sugar beet

The calculations were based on fairly conservative economic figures and prices in the 4 case regions. However, a further reduction in the price of RTK-GPS and other electronic systems in line with increased supply of these systems are expected in the future. Software costs were not explicitly included in this study, apart from the RTK software system. In this matter, some additional costs should be expected depending on the diffusion of the systems. Moreover, safety regulations for using these systems may be a further financial burden. To implement a complete independent and autonomous system, it will be necessary to include additional control and safety regulation and insurance costs depending on the task and location.

4. Discussion and future trends in crop production

Most new machines brought to the market are bigger than the previous model. When discussing this issue with equipment manufactures, this trend is likely to continue into the future. The driving force for this growth would seem to be to take advantage of the economies of scale that larger machines bring with them. This is easily demonstrated if the cost of the operator is taken into account. As most operators are paid by the hour, a larger machine that can increase the work rate over a smaller one can have a significant economic advantage.

The size increase does not only bring benefits. Large machines are only viable when working in large fields as turning, positioning and transport are all non productive activities. Although many farms have removed field boundaries to take advantage of the larger machines, many smaller farms cannot follow suite due to environmental concerns and suffer economically because of it.

As this equipment becomes larger, it also becomes very capital intensive with new tractors and combines becoming prohibitively expensive for the small and medium sized farm. Reliability also becomes an issue as all processes are carried out in series. If one part of the mechanisation system breaks down then all field operations stop.

An alternative approach would be to use available information technologies to automate these processes to the point where they do not need a human operator. By removing the person from the immediate control of the system, it offers new opportunities but also creates new problems.

Once the person is outside the control loop, then the economies of scale that applied to the larger, manned tractors does not apply and alternative smaller smarter systems can be developed. Work rates (per day) can be kept high by working longer hours and using multiple machines.

By taking a systems approach to designing robotic systems, consideration can be given to a system in terms of its action, interactions and implications. The result should be a new mechanisation system that collectively deals with the crop's agronomic needs in a better way than is done now. Most people define agronomic processes in terms of how they are currently carried out and a break from this mentality, or paradigm shift, is needed to define the processes in terms of the fundamental plant needs. When the plant requirements are defined independently of the machine that carries out the corresponding operations, this improved specification can be used in conjunction with mechatronic principles to help design smarter and more efficient machines.

In this study we have analysed the economic viability of two hypothetical autonomous robotic systems. In both scenarios we have replaced trivial labour intensive tasks for specific areas with autonomous systems based on highly accurate GPS-systems. These concepts and applications could be expanded to other field cultivation systems, tillage systems and grass cutting tasks at sport facilities and at public recreation areas. The autonomous weeding system with micro spraying in sugar beet may reduce the overall herbicide application with 90% and thereby improve the socio economic benefit. The autonomous field scouting system opens up the possibility for easier weed mapping, which again may give an incentive to conduct patch spraying in cereals and other crops. In addition, these robotic systems may further improve flexibility and expand the daily time constrains to night operations in the field and thereby improve the efficiency in modern crop production.

Based on the various systems and technical assumptions above, we have provided the potential economic viability of operating these systems compared to a similar treatment with conventional practices. The RTK-GPS system is still fairly expensive for these practices,

although the price is expected to be reduced as the technology becomes more widespread. The cost of receiving a GPS reference signal accounts for a significant share of the yearly costs for both systems – although both systems seem to be economically viable given the technical and economic assumptions above.
For both systems, we assume a depreciation period of 10 years. However, given the intensive utilisation of the robotic weeding system, it may be necessary to reduce the period of depreciation to about 5-8 y. In contrast, the autonomous field scouting system might have a longer lifetime than outlined above. It should also be possible to reduce field scouting costs by nearly 20 % in cereals and for the autonomous weeding in sugar beet, it might be possible to reduce costs by 12 %. For the latter however, it might be possible to reduce costs by 24 % compared to conventional treatment if inter-row hoeing could be reduced to only one treatment as for conventional weeding. In these calculations, we have used fairly conservative economic figures based on current prices. However, we may expect a further reduction in the price of RTK-systems and other electronic systems in line with increased supply of these systems. Software costs are not explicitly included in this study, apart from the RTK software system. Sensors for safety, such as ultrasonic, laser scanner, bumpers, were also not included in this study for the API platform not to further complicate the analysis, while they are very important for safety reasons In this matter, some additional costs should be expected depending on the diffusion of the systems.

5. Conclusions

An initial outcome from this study indicates that most of these autonomous systems are more flexible than conventional systems and may reduce labour costs and restrictions on the number of daily working hours significantly. Moreover, it is possible to substitute the most trivial working routines with autonomous systems although some routines are nearly impossible to automate due to the required accuracy of the specific tasks. In addition, at this stage of development, the initial investments and annual costs for expensive GPS systems are still relatively high but it seems possible to design economic viable robotic systems for grass cutting, crop scouting and autonomous weeding.
Findings show that there is a significant potential for applying these systems if it is possible to impose adequate control and safety regulations systems at reasonable costs. Moreover, a comparison between different European countries indicates that labour costs, crop rotation and farm structure may have a tremendous impact on the potential use of these systems.

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The aim of this book is to provide new ideas, original results and practical experiences regarding service robotics. This book provides only a small example of this research activity, but it covers a great deal of what has been done in the field recently. Furthermore, it works as a valuable resource for researchers interested in this field.