

Sustainable Precision Agriculture:
Research and Knowledge for Learning
how to be an agri-Entrepreneur

ROBOTICS FOR FUTURE AGRICULTURE

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1 INTRODUCTION

The aim of Work Package 2 of the SPARKLE project is to prepare supporting documents for Precision Agriculture (PA) education on two main elements: future trends (technological foresight and focus on Robotics) and successful companies' business models.

This report aims to underline and document the first element of this objective by reviewing the current State-of-the-Art technology as well as the forecast for its future within the agricultural robotics sector.

1.1 TARGET AUDIENCE

As explained in [1], awareness alone is not likely to have an impact on Precision Agriculture adoption, however, the amount of information about the subject is often insufficient and too dispersed to be able to make proper choices [2]. Therefore, the target audience of the SPARKLE project is anyone interested in PA, but in specific agriculture students and farmers who are interested in the technology, as well as in the entrepreneurial aspect.

While the aim of the project is to produce material for a PA course, this report functions as a base for what content would be relevant within such course. Therefore, this report's aim is twofold:

- Inspiring people to follow the course once completed;
- Informing the public in general of the relevant subjects within PA.

1.2 BACKGROUND

While mechanisation of agriculture saw a boost in the early 20th century with the introduction of the tractor, it is now turn for the agricultural robotics market to grow rapidly. However, due to the generally conservative nature of farmers, adopting automation and robotics is a demanding task, which requires attention to assure acceptance. Moreover, as with any business, financial implication of any adoption influence the choice more than social or environmental ones. This is also confirmed in [1] where credit availability has a significant correlation with adoption probability. Economic policies like subsidies are a good example of this trend as well. In addition, international technological trends are often set by the large manufacturers, due to their broad network.

Another important aspect to understand the current agricultural situation, is the way of adopting technology: buying and maintaining the product, or buying a service contract. When developing new technologies, the choice between service or product might influence its success. While both ways are common practices, in general, a task (like harvesting or weeding) can be carried out as a service, and an action (like cutting or spraying) can be sold a product. An interesting result from [3] is that the likelihood of adopting PA is significantly higher for contractor services than for farmers in other branches.

Nevertheless, some trends cause an imminent need to adopt some sort of automation. An example is the labour shortages within several sectors resulting in unharvested crops, as for example in the UK [4], Australia [5], and the USA [6], it is expected to grow even more in the next decades. Although automating harvesting tasks seems to be the main opportunity defined by these examples, many other tasks follow due to the increasing demand to produce more with less.

Lastly, let us define what we mean with agricultural robotics in this document. The general definition of a robot is a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer [7]. This means that any machine that takes sensory input, takes a decision based on that input, and then actuates accordingly, is considered a robot. In agricultural context, a robot carries out an operation without manual intervention. Often robots are used to automate repetitive, hazardous, and/or easy operations, to make the overall agricultural task more convenient for the farmers.

1.3 DOCUMENT STRUCTURE

For robotics to be a feasible alternative to the current way of working, it is important to be aware of the benefits of these alternatives, as well as knowing the current and future market trends. For this reason, this report provides an overview of the current State-of-the-Art and current research, organized in three key topics within agriculture robotics:

1. **Mobility and locomotion**
Discussing the way robots move from place to place.
2. **Manipulation and actuation**
Discussing the way robots act on their environment.
3. **Swarm and multi-robot systems**
Discussing the specific field of managing fleets of robots.

Although we often classify perception and sensing separately, this report discusses it within its application. Moreover, even though pure software and big data solutions are important in current advancements, this document only focusses on robotics, and therefore system solutions (combined hardware and software).

The following chapters discuss each of these three topics in more detail.

2 MOBILITY AND LOCOMOTION

When looking at a production setting, where automation is widely adopted, a product generally moves through a robotic environment, whereas on the field, the opposite is true: the machine or robot needs to move through a fixed orchard or between crops. Moreover, agriculture is a challenging environment for autonomous vehicles, considering the challenges arise when taking into account the dynamic environment. In fact, autonomous navigation in outdoor environments has been the subject of intensive research in a number of applications.

Nevertheless, recently indoor agriculture is expanding, while shifting towards moving the crops as well in a production-like setting. In general, indoor farms like greenhouses have proven to be better suited for automation due to their semi-rigid framework with well-defined boundaries.

2.1 CURRENT STATE-OF-THE-ART

Many current technologies build on pre-existing platforms such as drones and autonomous tractors. This makes it impossible to optimise some functions, and even implement others. A good example of this is the Cerescon Sparter [8], which carries out the harvesting task autonomously, but requires a tractor for locomotion. Nevertheless, many new start-ups have risen in the last few years who created entire platforms to fit their every need. For example, the fully autonomous Agrobot [9] has a “flexible” platform, which is mendable to fit the farmers’ configuration.

Twenty-one tools, deemed state-of-the-art, have been analysed on both their locomotion and their manipulation capabilities. Appendix A shows an overview of these tools. They either are prototypes or recently rolled out products. One of these products has an unknown way of moving, and is therefore disregarded in this section.

For the goal of this research, Table 1 shows a 5-point scale, which defines a machine’s autonomy level in locomotion. Whenever it is uncertain in which category a tool falls, we classify it in the lower one. For example, if according to specification a tool has a camera, but no mention on how it’s used, the assumption is made it is not fully aware of its surroundings.

Table 1. Autonomy Scale and Definition for Locomotion of Agricultural Technology

1 Fully Dependent	2 Semi-Dependent	3 Intermediate	4 Semi-Autonomous	5 Fully Autonomous
Driven, not aware of surroundings	Driven, partly aware of surroundings	Partly self-driving, partly or not aware of surroundings	Self-driving, partly aware of surroundings	Self-driving, fully aware of surroundings

Figure 1 shows the distribution of the categorised state-of-the-art technology within the defined scale. Because the tools are fully functioning machines, some of them focus on the manipulation aspect, which lowers their score on the locomotion scale. Nevertheless, category 4 contains the bulk of the machines, due to the high demand in autonomy. The reason many examples do not classify as fully autonomous, is that insufficient information is available to assume the machines are fully aware of their surroundings.

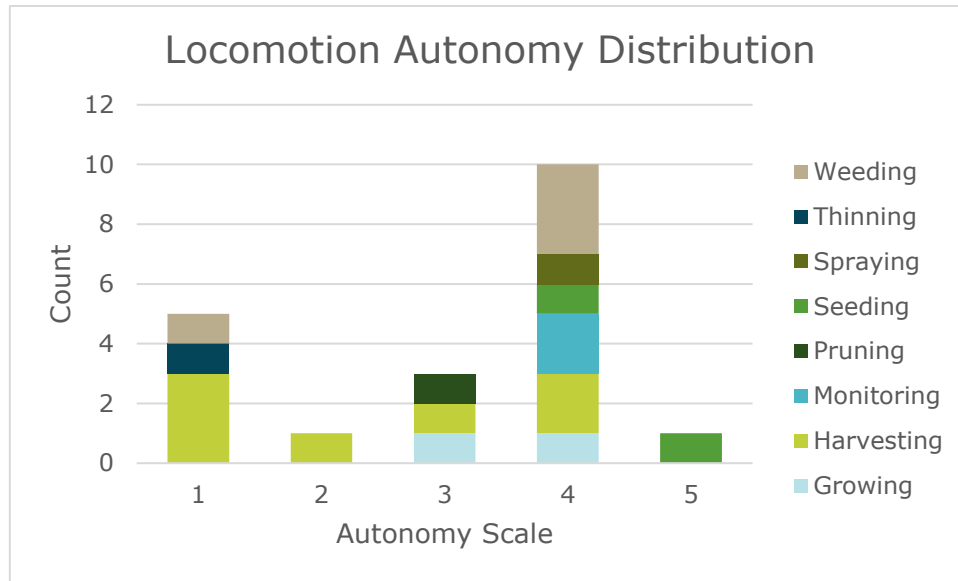


Figure 1. Distribution of Locomotion of State-of-the-Art Agricultural Technology

When looking at the more autonomous categories (4 and 5), certain technologies play an important role in allowing systems to fulfil their duties, with many of them greatly depending on the system's knowledge and perception of its location.

GEOLOCATION

An important aspect for farmers to be able to integrate the technology in their current ecosystems is geolocation. As farmers decrease in numbers, plot sizes increase, and new systems need efficient methods to find their way through the fields. A combination of high precision GPS and intelligent software can quickly calculate the most efficient routes to follow, and recalculate in unforeseen events. Current manufacturers invest a lot in creating such systems [10]. Nevertheless, most of the analysed prototypes only drive within semi-fixed environments, giving them less freedom to optimise.

RELATIVE LOCATION

Besides absolute positioning, autonomous systems also depend on local environment perception, or relative positioning with respect of crops. Within this aspect, technology varies considerably from visual to tactile perception. Although tactile perception is not well suited to assure human safety, its use can be favourable when moving along semi-known environments such as orchards and greenhouses due to their lower costs. Nevertheless, non-tactile sensing seems increasingly popular, with its uses growing due to developments in so-called artificial intelligence. Obstacle recognition based on cameras or LIDAR systems and path planning based in a precise map are widely used in the analysed systems. Moreover, the actuation and manipulation systems often use the same sensors for their object detection and estimate the relative location of the tool with respect to the crop.

WAREHOUSE APPROACH

Lastly, one technology gaining traction is the indoor farming sector where greenhouses adopt a manufacturing or warehouse-like approach. Here small transport vehicles move the plants to the proper location based on the required actions. These systems tend to use distinct local positioning systems or guide rails, but the addition of vision contributes to the human-safety aspect.

Note that many of the currently used technology builds around the current infrastructure. Farmers cannot change their entire way of working, and need new technology that takes its place within the existing framework.

2.2 FUTURE TRENDS

Within the previously mentioned areas, multiple investigations have paved the road for future agricultural robotics.

GEOLOCATION

In recent studies, scientists [11] propose a way of combining GPS data with a magnetometer and wheel encoder systems, to increase the precision. Future implementations of combined position measurements will improve geolocation to sub-centimetre accuracy levels.

Another approach, as proposed by [12, 13], would be combining information from multiple sources. The studies propose frameworks combining data from ground and air vehicles, which outperforms several state-of-the-art techniques. This opens the opportunity for swarm robotics and enables reducing robot sizes in favour of lower soil compaction.

Lastly, studies within the path-planning field propose ways to take into account more variables, and optimise the route for a larger number of resources [14, 15].

RELATIVE LOCATION

To improve relative positioning, robotic systems need to sense their direct surroundings. Object detection and path adaptation are important to avoid running over (parts of) plants and therewith for higher yields. Moreover, object detection is also crucial for human safety around autonomous systems. Conducted research show great improvement in autonomous decision-making based on vision [16, 17, 18], or other optical sensors [19]. Resulting technologies will expectedly reach high efficiency real time applications soon, ensuring implementation of autonomous decisions.

In general, as computational power grows, calculations can interpret more information and become more effective. In addition, farmers' increasing trust in these robotic systems causes autonomy to be more widely accepted.

2.3 CLOSING WORDS

As systems carry out more and more tasks autonomously, two paths are likely to emerge. First of all, autonomous multi-purpose vehicles and tractors, which can build on the current infrastructure. Second would be a diverging path towards many single-purpose self-driving robots. The latter path, being superior in many ways, requires adaptation and sacrifices from the current way of working. Both options have their own benefits, but a combination of the two is also likely.

Within the locomotion and mobility topic, it is advised to consider aspects like recent crop-management software, path planning and optimisation, and machine learning concepts for precision agriculture courses. It is likely these topics take an important place within the architecture of future robotic systems, especially within the positioning techniques.

3 MANIPULATION AND ACTUATION

Robots working in agricultural tasks are usually composed of two parts. First off is the platform of movement, discussed in the previous section. The second part is usually an integrated tool that allows the robot to carry out a certain task. Figure 1 already introduced several of these possible categories of tasks, but Table 2 shows the full list.

Table 2. List of Defined Agricultural Tasks

Task Group	Task
Prep & Seeding	Tillage Seeding
Crop Care	Fertilising Irrigation Weeding Mechanical / Chemical Crop Protection (Sprayers) Pruning / Thinning Monitoring
Harvest	Harvesting (Selective) Transportation (In-Field)

Technology used these days consists of many individual actions, often mimicking the human ones. However, considering the dynamic nature of the environment, mostly due to the growing of plants, pre-programming the manipulation action is not a simple task. A robot needs to be capable of adjusting to a wide variety of scenarios. Often the actuation links closely to the perception modules for feedback.

3.1 CURRENT STATE-OF-THE-ART

Many agricultural tasks happen in a fixed sequenced order, for example the three steps carried out by a combine harvester. This makes it possible to automate the actions solely depending on autonomous locomotion. For this reason, the manipulation analysis views the actions independently from locomotion. Table 3 shows the same 5-point scale, however, this time defined for the autonomy within manipulation.

Table 3. Autonomy Scale and Definition for Manipulation of Agricultural Technology

1 Fully Dependent	2 Semi-Dependent	3 Intermediate	4 Semi-Autonomous	5 Fully Autonomous
Actions fixed, without taking into account the surroundings	Actions fixed, partly taking into account the surroundings	Partly independent, partly or not aware of surrounding	Autonomously choosing actions, partly aware of surroundings	Autonomously choosing action, fully aware of surroundings

Figure 2 shows the categorisation of this autonomy aspect of the twenty-one systems mentioned before. Here we disregard two products due to the lack of mechanical actuation.

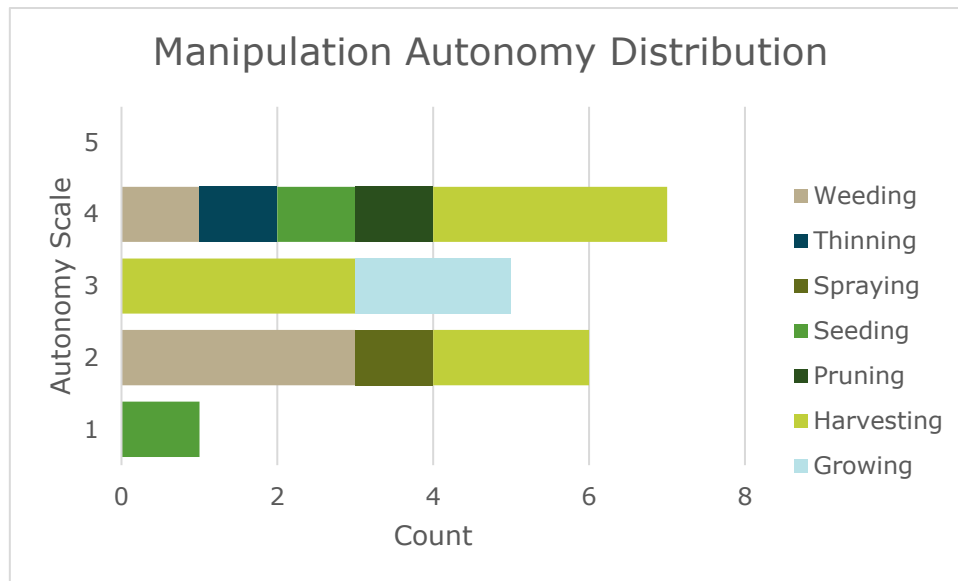


Figure 2. Distribution of Manipulation of State-of-the-Art Agricultural Technology

Here the results are more spread out, assumed to be caused by the fact that locomotion is the leading factor in automating many tasks. For example, a self-driving tractor pulling passive implements could be considered automated, nevertheless, the farming action itself has a low level of autonomy.

Combining the two created charts, and displaying each system as one dot, creates the graph depicted in Figure 3.

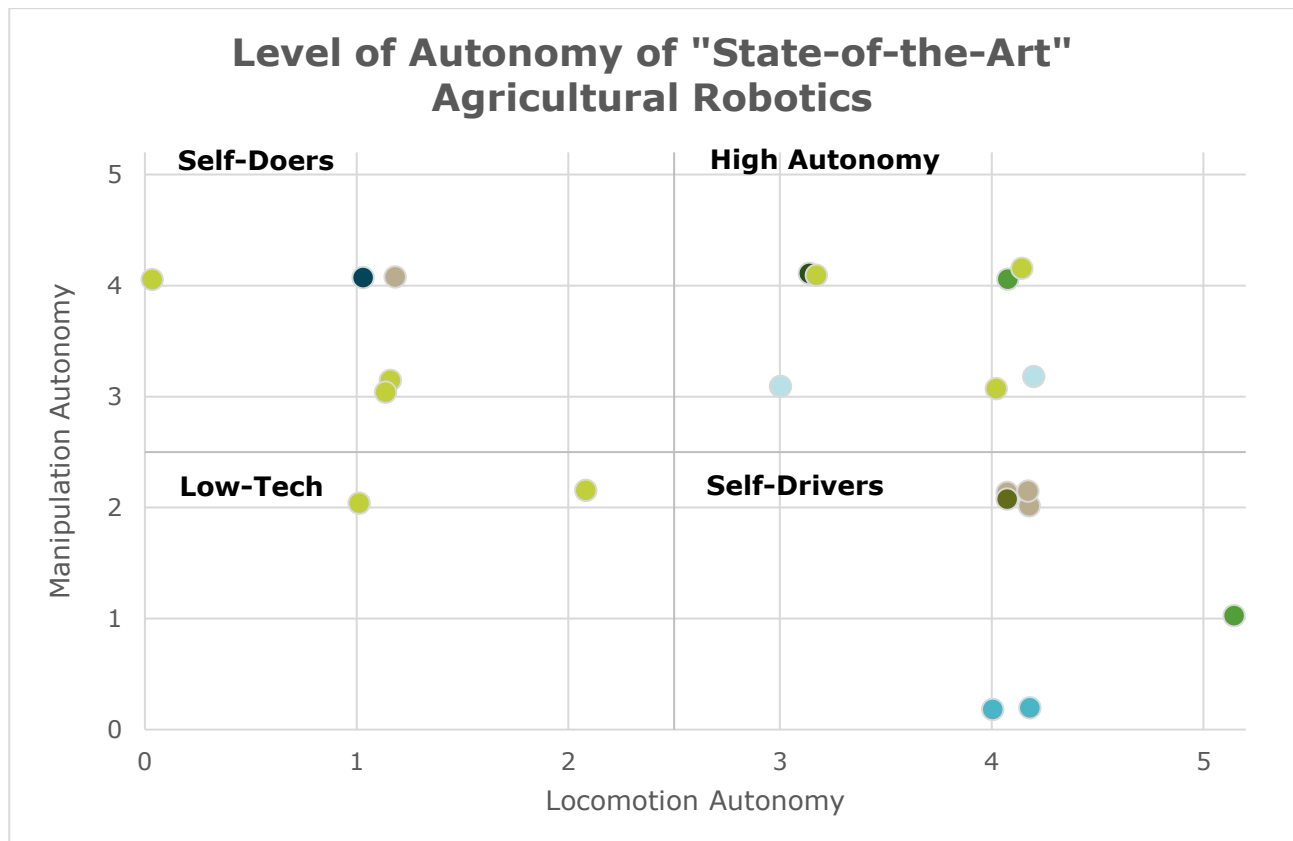


Figure 3. Scatter plot of State-of-the-Art technology in their Autonomy Levels

When looking at the more autonomous categories (4 and 5) within the manipulation topic, certain technologies play an important role in allowing systems to fulfil their duties. Again, many depend on the system's perception capabilities, but a second important aspect is the ability to perform precise and delicate actions.

PERCEPTION

Many of the manipulation actions require advanced perception and image processing. Tasks like harvesting or weeding require robots to differentiate between objects with subtle differences. Resulting systems therefore often use machine learning and other artificial intelligence implementations to recognise, categorise, and actuate accordingly. Although already reaching high accuracy and sensitivity levels, current systems can still improve a lot in (processing) speed.

ACTUATOR POSITIONING

Due to slow processing of the perception of the immediate environment, movements tend to be slow as well. Even though slowness adds perspective to the decision-making and gives time to act, society considers it a hurdle for the adoption of autonomous systems. Nevertheless, many systems and prototypes do have very advanced ways of carrying out tasks. In general, robotic arms position the tools with respect to their destination. Some systems have very restricted movement possibilities to reduce complexity, while others add software restrictions to ensure movement within a safe-zone. In most cases, though, the systems are designed to reduce the chances of unintentional contact with the plants.

DEXTERITY

Lastly, an aspect necessary for manipulation is the dexterity of the action. A wide variety of specific tools exists to perform tasks like harvesting, seeding and weeding. Many companies use and experiment with soft grippers, making sure not to harm the produce, while others only grab produce at the stem. Both ways require precise positioning and movements. Other specific precision tools consist of sprayer and (single seed) sowers. In most tasks other than harvesting, dosage is an important aspect. Modern farming requires yields to increase, while reducing costs and wastes. Precise application and measurements are therefore increasingly valuable.

3.2 FUTURE TRENDS

Within the previously mentioned areas, multiple investigations have paved the road for the future agricultural robotics.

PERCEPTION

Within this area, research often combines local and global positioning of a system, since a combination increases the total positioning accuracy. Therefore, aforementioned research (in Section 2.2) also applies to local perception. For example, [16] and [19] both propose ways to improve the global positioning via recognition of objects within the local environment. Nevertheless, some studies do solely focus on perception with

the goal of actuation, using ultrasound sensors [20] or cameras. The latter often focusses improving object detection and categorisation using neural networks, machine learning or other image recognition techniques [21, 22, 23, 24, 25, 26].

ACTUATOR POSITIONING

As explained in the State-of-the-Art section, many solutions use robotic arms to position their tools, which is reflected in the scientific world, where precise control guarantees unharmed produce. Examples of such research are [27], where damage reduction is a priority, and [28], where robotic arms shape according to the tree. Furthermore, studies like [29] show promising first results for the future of robotic arms in full or semi-automatic processes.

DEXTERITY

The last area important to manipulation is the dexterity of the tool. Primarily tools that physically interact with the plants need a design such that they do not harm the produce or the crops in any way, which would cause a reduction in yield. Examples include [30] for manipulation and transplantation of seedlings, [31] for soft grippers, and [32] for force regulation. Other examples of innovative graspers are developed as well [33], although not specifically for agricultural purposes. Lastly, [34] and [35] discuss precision spraying of plant protection products.

3.3 CLOSING WORDS

While technology shrinks and actions become more precise, agriculture can adopt robotics in more sectors. Within the manipulation topic, there are two main routes for automation: automating manual labour and automating passive technology. The latter mostly requires autonomous vehicles to carry the passive tools, while the former requires specific tools, or artificial body parts to recreate the human actions. In both cases, selective actuation is becoming increasingly popular, leaving unripe harvest to ripen on the plant. This means perception within this topic is also of increasing importance, to add highly detailed differentiation possibilities.

Enabling technologies, advised to consider for precision agriculture courses, are the Internet of Things (IoT), Machine and Deep Learning (Convolutional Neural Networks), and non-invasive sensors in general to understand sensing and decision making of robotic systems. Furthermore, modelling and control of dynamic elements proves to be important to make robotic movements more precise, and good understanding of material science is crucial to mimic human processing of crops, or even improve within this field.

4 SWARM AND MULTI-ROBOT SYSTEMS

Systems composed of multiple robots are becoming increasingly popular, in the last few years. The advances that have made individual robotics systems more practical have enabled the research on and the development of cooperative robots, where the collective actions of the swarm define the capabilities rather than the individual actions. This is especially relevant in complex tasks that require varied capabilities in both quantity and difficulty. Moreover, one of the main advantages of having a cooperative system instead of a super-capable individual is in the increased reliability due to redundancy. While most works address the problem of controlling groups of homogeneous robots, a few researchers have recently provided solutions for controlling groups of heterogeneous robots.

4.1 CURRENT STATE-OF-THE-ART

Cloud solutions provided by many of the larger agricultural technology companies, have enabled them to produce self-driving tractors, which can function autonomously using traditional equipment. Moreover, many of these solutions provide possibilities for swarm options. Nevertheless, these options are often costly, which makes other solutions increasingly interesting.

4.2 FUTURE TRENDS

Within the swarm robotics trend, research mainly focusses on the management and collision avoidance of the systems. Examples are [36] and [37], proposing to minimise data transfer and increase bias and redundancy to maximize knowledge. Moreover, [38] proposes ways to combine unmanned ground and aerial vehicles in several different application environments. Lastly, studies like [29] base their design choices on possible fleet implementation.

4.3 CLOSING WORDS

Choosing to automate agricultural work opens the door to 24h farming. In contrast to recent growth of machinery, this actually allows for a smarter, decentralised approach. In its turn, making improvements to currently impossible or costly aspects like reducing ground pressure and reducing downtime. Swarm robotics also adds benefits with respect to redundancy, scalability, and energy consumption.

Swarm robotics is an interconnected topic of multiple technologies and disciplines. It is advised to consider this topic as a whole for precision agriculture courses, learning about the framework of Internet of Things (IoT) and data processing, as well as about the benefits of decentralised operations.

5 CONCLUSIONS

Robotics will undeniably play a great role in the future of agriculture. It is therefore important for future farmers to invest in knowledge of these technologies, and understand what this technology can mean for them. This report discussed several topics, describing the importance of various technologies and their possible impact on the future of farming.

In line with the objective to prepare supporting documents for precision agriculture education, we advise to focus on several concepts and learning themes. In general, these fall into four topics deemed crucial for the future of agricultural technologies:

- **Algorithms and Optimisation**

Learning about crop management, path planning and optimisation of tool usage. Also preventive maintenance to tools and optimising harvesting yields.

For people with agricultural backgrounds it is advised to understand the benefits and basic concepts behind optimisations. Focussing on the question: why trust them, even when they seem counterintuitive? For people with engineering backgrounds, it is important to understand the aspects that need to be taken into account in these optimisation, like soil compaction, fuel consumption, and actuation necessity locations.

- **Sensing and Processing**

Learning about non-invasive sensing techniques like LIDAR, GPS/GNSS, Kinect and other light or sound sensors as well as how to process this data using modern software solutions and concepts such as Internet of Things, Machine/Deep Learning (Convolutional Neural Networks), and other data analyses.

For people with agricultural backgrounds it is important to focus on the added benefits of new sensing techniques, such as better precision or better understanding of the crops needs. The latter is also important for engineering backgrounds. Understanding the basics and the necessities for the implementation of processing algorithms is also important, such as the categorisation of a base set before adopting machine learning.

- **Dynamics in Robotics**

Learning about material sciences and control of dynamic elements. This topic should also address ways to improve actions by looking at the basic needs of the action instead of building on the existing tools or human actions.

People with agricultural backgrounds should focus mainly on the understanding of the limitations and challenges in both software and hardware of robotic parts. The focus for people with engineering backgrounds are the dynamic needs of the environment undergoing actuation.

- **Swarm Robotics**

This topic should address aspects of swarm robotics and multi-robot systems such as maintenance, communication and management. Also discussing the other benefits and improvements.

Here people from either background should learn about the way swarms operate, and their added benefits with regard to redundancy, continuous operability, and their distributed nature. Also it is important to understand the consequences of such introduction with respect to implementation, management, and operation. The possible shift towards service providers and the requirement of a industry wide standard for data management.

We believe that covering these four topics in an advanced precision agriculture course would improve understanding and acceptance of high-tech robotic systems within that field. Moreover, it is important that the course covers aspects for all backgrounds, to make sure it can reach a large audience.

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Appendices

APPENDIX A. STATE-OF-THE-ART

As explained in Sections 2.1, 3.1, and 4.1, twenty-one products have been categorised on basis of their autonomy in locomotion and manipulation, as well as for their ability to work in fleets. Table A 1 shows this overview.

Table A 1. Overview State-of-the-Art technology, including hyperlinks to websites and videos, classified for autonomy levels.

Type of Crop	Action	Company / Project	Website ¹	Video ¹	Locomotion	Manipulation	Fleets
General	Weeding	Blue River Technology	link	link	1	4	1
Grapevine	Weeding	Vitirover	link	link	4	2	2
General	Weeding	Naio Oz	link	link	4	2	1
Grapevine	Weeding	Naio Ted	link	link	4	2	1
Lettuce	Thinning	Vision Robotics	link	link	1	4	1
General	Seeding	Fendt, AGCO	link	link	4	4	3
General	Seeding	Dot/ Seedmaster	link	link	5	1	1
Grapevine	Pruning	Vision Robotics	link	link	3	4	1
Grapevine	Monitoring	Vinbot	link	link	4	N/A	1
Grapevine	Monitoring	VineRobot	link	link	4	N/A	1
Orchards	Spraying	GUSS	link	link	4	2	1
Grapevine	Harvesting	Pellenc	link	link	2	2	1
Asparagus	Harvesting	Cerescon	link	link	1	3	1
Strawberry	Harvesting	Harvest Croo	link	link	4	3	1
Strawberry	Harvesting	Agrobot	link	link	4	4	1
Lettuce	Harvesting	Ramsay Highlander	link	link	1	2	1
Apple	Harvesting	FFRobotics	link	link	unknown	4	1
Apple	Harvesting	abundant robotics	link	link	1	3	1
Peppers	Harvesting	Sweeper	link	link	3	4	2
Leafy Greens	Growing	ironox	link	link	4	3	2
Leafy Greens	Growing	technofarm	link	link	3	3	1

The following sections of this appendix contain general elaboration of the ability and the scores of these technologies.

Note, that even though some examples might not fully met our definition of robots, they do reflect the common way agricultural tasks are being automated. Therefore, these machines are taken into account as comparison material for the rest.

¹ All hyperlinks checked on 29-07-2019. Download pdf from <http://sparkle-project.eu/> if hyperlinks do not work.

BLUE RIVER TECHNOLOGY

Using computer vision and artificial intelligence, this start-up is aiming to revolutionise agriculture by reducing the amount of substance needed to carry out tasks. The “See & Spray” technology recognizes good from bad, and only sprays where necessary, claiming to being able to reduce herbicide costs by 90%, and therefore fighting herbicide resistance.

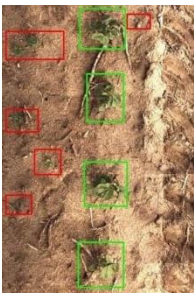
Autonomy Scores

Locomotion: 1

Manipulation: 4

Fleet: 1

This technology received a low locomotion score due to its pure manipulation focus. Within manipulation autonomy, it scored very well, but slightly fell short of a full score because of the uncertainty around its full awareness. Lastly, it is not designed for fleet interaction at all, although multiple units could be used at the same time, the fleet management is needs to be carried out separately.



VITIROVER

This small and lightweight piece of equipment is actually an advanced lawnmower type machine, which mechanically removes weeds between the rows of vineyards. The focus of this solution is to reduce glyphosate and other herbicides, effectively by not allowing weeds to grow.

Autonomy Scores

Locomotion: 4

Manipulation: 2

Fleet: 2

This technology received a high score in locomotion, but did not hit the top mark due to the uncertainty of its awareness of the surroundings. No information is given on if or how different robots can detect and avoid each other, nor if they communicate at all. This also clarifies the middle score in fleet operation. When it comes to manipulation, this system scores low due to the semi-fixed mower.



NAÏO OZ

This small robot helps farmers in their daily weeding and hoeing chores but can also be helpful for carrying loads and following you around during harvesting. It comes with a variety of tools designed to plough and weed between and within crop rows. Its broad employability is one of its strong point, which can make it worth an investment.

Autonomy Scores

Locomotion: 4

Manipulation: 2

Fleet: 1

The locomotion score is pretty high, as this little robot can drive autonomously, but did not hit the full score due to the uncertainty of how well it understands its environment, and whether it recognizes obstacles. The manipulation is carried out in a semi-static way, which results in a humble 2. As far as fleet operation goes, no information is given, and as such it is assumed as not implemented.



NAÏO TED

The big brother of the OZ, specifically created to weed in vineyards and claimed to be able to maintain a surface of about 25Ha by itself. The outlook is for this robot to also thin and trim the plants. Although not explained, artificial perception technology seems to be included according to the pictures. This piece of technology is due to change modern viticulture.

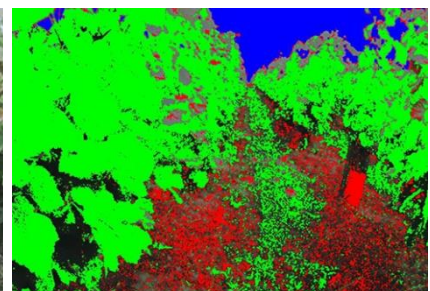
Autonomy Scores

Locomotion: 4

Manipulation: 2

Fleet: 1

Like OZ, TED doesn't get a full 5 point for locomotion due to the lack of explanation of its capabilities. This also holds for its mainly fixed manipulators, and therefore its modest 2. This score could improve sooner than later, if the artificial perception is used to carry out the tasks localised and precisely. Lastly, this product is not designed for fleet operation.



VISION ROBOTICS LETTUCE THINNER

This machine carries the task of identifying and removing the unwanted plants automatically, making the manual thinning task completely obsolete. It is based on artificial perception to correctly identify the correct plants. Vision Robotics claim that the payback time can be as short as a few months when compared to hand labour.

Autonomy Scores

Locomotion: 1

Manipulation: 4

Fleet: 1

Due to its design as an implement, it scores low on locomotion autonomy. Nevertheless, it greatly makes up for this within the manipulation score by using artificial perception to identify good from bad plants in real time and actuating precise sprayers to apply products. Lastly, this product is not designed for fleet operation.



FENDT, AGCO XAVER

This fleet design for seeding application is an example of the possibilities cloud computing and decentralisation can offer agriculture. Although not yet entirely publicly available, the first parties are currently using and testing these systems. Among other benefits are reduced power consumption, lower emissions, lower soil compaction, and round the clock working.

Autonomy Scores

Locomotion: 4

Manipulation: 4

Fleet: 3

The autonomy scores reflect the high autonomy of this system. Nevertheless, the lack of information provides the suspicion that the systems are not fully aware of their surrounding in neither locomotion nor manipulation. In the end, the focus of the project is reflected in its full score for fleet operation. The individual robots are continuously communicating and information is shared with an overall decision making system.



DOT/SEEDMASTER

This vehicle reimagines the modern day tractor. Capable of carrying implements and performing any task allowed by the chosen implement. It has been completely designed from the bottom up, resulting in several benefits. The total weight can be drastically reduced because implements can function their own, autonomously, instead of being pulled. It claims to reduce the power and fuel usage by 20%.

Autonomy Scores

Locomotion: 5

Manipulation: 1

Fleet: 1

The locomotion autonomy score of this vehicle reflect its power to move completely autonomous. According to the available information, it is able to precisely know its location and is aware of its surroundings. The manipulation score is based on its first implement (a mechanical sower), which functions as a regular mechanical implement.



VISION ROBOTICS GRAPEVINE PRUNER

Although still in development, this pruner is very promising. It “sees” and recognises individual branches, and determines where to prune. Although being developed for the manipulation aspect, the system also comprises of a self-driving vehicle to pull the implement. This technology is of great interest to automate a very repetitive task.

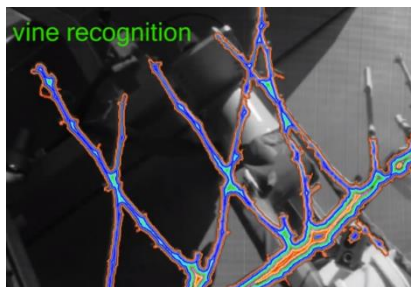
Autonomy Scores

Locomotion: 3

Manipulation: 4

Fleet: 1

Although the main focus lies in manipulation, the project has focussed on an autonomous vehicle. Like in their other product, the Vision Robotics team focusses on artificial perception and autonomous decision making. This system uses a sophisticated method to recognize the branches and decide which to cut. Fleet operation is not considered within this product.



VINBOT

This little robot is a product of a European consortium, and is used to monitor vineyards. Within viticulture it is increasingly important to monitor the crops in order to assure a certain level of quality. The robot gathers 3D and colour data, which can be analysed separately for example to calculate leaf-to-fruit ratio.

Autonomy Scores

Locomotion: 4

Manipulation: -

Fleet: 1

The autonomy scores of this vehicle reflect that it can move autonomously, however is uncertain to what extent it can understand its environment. Furthermore, because it does not carry out any mechanical action, the manipulation aspect is not considered, as it is not considered robotic. Lastly, this vehicle is not designed for fleet operation.



VINEROBOT

Similar to VINBOT, this system is designed to monitor vineyards. It gathers data about vegetative growth, grape composition and yield, which is used to later improve the cultivation, optimising vineyard management and improve quality.

Autonomy Scores

Locomotion: 4

Manipulation: -

Fleet: 1

This robot is designed with data gathering in mind. This has the advantage that many sensors are available in general, and many are used for autonomous driving as well. This results in the current locomotion score. As for manipulation, no physical action is carried out, and is therefore not taken into account. Also fleet operation is not implemented in this design.



GUSS

An interesting robot is GUSS, the autonomous orchard mist sprayer. This system removes the farmer or worker exposure to applied products, thus ensuring their safety. Moreover, it can spray very precise quantities, therefore reducing the amount of applied products.

Autonomy Scores

Locomotion: 4

Manipulation: 2

Fleet: 1

This robot mainly focusses on autonomous locomotion. Because it is unsure how well it can coop with uncertainties, it did not get a full score. Its manipulation is semi-rigid with a couple of parameters that may be changed. It is mentioned, however, that some aspects can be taken into account, spraying certain parts differently than others, resulting in the current manipulation score.



PELLENC OPTIMUM

This grape harvester is an example of the way larger vehicles are using automation. Although this machine still needs a driver, it is said to improve productivity by 25% as well as greatly reducing in fuel consumption. It also automatically sorts the harvest to guarantee very high cleanliness standard.

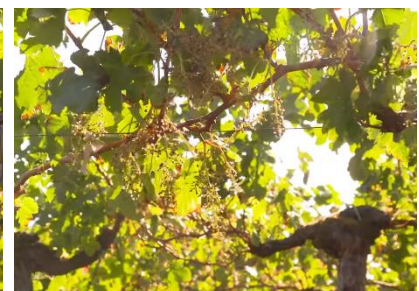
Autonomy Scores

Locomotion: 2

Manipulation: 2

Fleet: 1

Although not designed to drive by itself, this vehicle does make it easier for the driver with many driver assisting technologies. This also holds for the manipulation aspect, where most of the actuation is performed in a semi-fixed mechanical manner. For example, all parts of the plant are touched, not only the parts containing harvest. Lastly although this vehicle can be used in fleets as displayed, but does not account for sharing data. All fleet operations need to be managed separately.



CERESCON SPARTER

It's still very common for asparagus to be harvested by hand. This back-breaking, time consuming way of work is drastically affected by the introduction of this piece of technology. This apparatus not only harvests automatically, but selectively, leaving the non-mature crops in the ground, and repairing the sand bed.

Autonomy Scores

Locomotion: 1

Manipulation: 3

Fleet: 1

This is a great example of how a big impact can be achieved without adopting full autonomy. This system is designed as an implement and therefore scores low on locomotion. The manipulation aspect is semi rigid, where the picking is performed according to the location, but all the other actions are performed fixed.



HARVEST CROO

This strawberry harvester is designed to be as least disruptive to the current way of working, by mimicking the human way of picking. This way, farmers may continue growing in the same way, without the need of changing all their equipment. They claim that a single machine harvests 8 Acres a day, and represents 30 human pickers.

Autonomy Scores

Locomotion: 4

Manipulation: 3

Fleet: 1

Although the machine does not require a driver, it is unsure to what extent it is aware of its surroundings. The manipulation aspect also is semi-rigid with a clear boundary of its current capabilities. This system is a good example of achieving a big impact without disrupting the way of working. Fleet operation has not received any focus.



AGROBOT

The second strawberry harvester in this list, is designed from a completely different perspective, and is a bit more disruptive. It requires the fruit to hang away from the plant, but compensates by using up to 24 robotic arms simultaneously. It detects ripeness and leaves unripe fruit on the plant, and even claims being able to harvest the fruit in three different ways, with or without stem or calyx.

Autonomy Scores

Locomotion: 4

Manipulation: 4

Fleet: 1

The autonomy scores for this system are as high as you would expect. Because of lack of information about its awareness of the surroundings, no full points are awarded. As for manipulation, this system does very well but also misses a full score because of no proof of having an overall perception of the plants. Lastly this system does not mention any possibility of fleet operation.



RAMSAY HIGHLANDER

This romaine/lettuce harvester uses water jets to cut and harvest large quantities of leafy greens. This system is a good example of labour improvement, as still humans are necessary to pick and pack the produce, their circumstances are greatly improved, not needing to crouch all day. In short, this is a mechanical improvement for the workforce.

Autonomy Scores

Locomotion: 1

Manipulation: 2

Fleet: 1

As a driver is needed, and no information is given on any drive assistance, and thus a low dependant locomotion score. As for manipulation, this system uses a semi-fixed way of working, and labourers to finalise the work. Lastly, there is also no mention of fleet operation.



FFROBOTICS

This company offers a robotic fruit picking solution using image processing to be detect and pick produce in a bruise-free way. The system claims to be 10 times more productive and faster than human picking. Moreover, it enables data collection and analysis of fruit per tree, which can in its turn help in decision making.

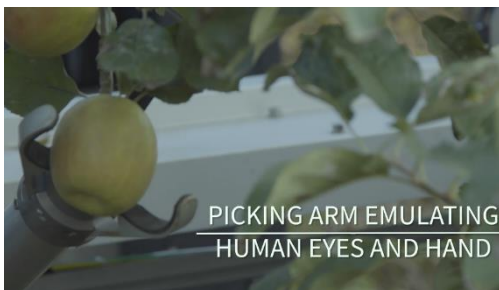
Autonomy Scores

Locomotion: -

Manipulation: 4

Fleet: 1

Unfortunately, this system does not disclose any information about the way of locomotion. Therefore, it has not been assigned any category. The manipulation aspect of this robot, on the other hand, is quite automated. Using image processing techniques to identify and classify the fruit and harvest selectively. Fleet operation is not mentioned, however, multiple arms per system could drastically improve speeds.



ABUNDANT ROBOTICS

The second apple harvesting equipment in this list, is based on a completely different picking mechanism. This machine uses a vacuum-cleaner type apparatus to pick the fruit instead of a conventional gripper. These type of systems will definitely play an important role with the decreasing number of fruit pickers and the increasing demand.

Autonomy Scores

Locomotion: 1

Manipulation: 3

Fleet: 1

Although self-driving is mentioned in some articles about this technology, the system is built as an implement, and the main focus lies on the harvesting and not on the driving. The manipulation here consists of image recognition and a vacuum tube. It is not sure how precise the machine is in its picking process, and therefore got categorised in the middle. Lastly, fleet operation is not mentioned.



SWEEPER

This bell pepper harvester is a great combination of both autonomous driving and manipulation. Using image recognition techniques to detect, localize, and classify maturity of the produce this system works independently of surrounding light conditions. Moreover, this system is designed to operate in narrow environments, without harming the plants and produce surrounding it.

Autonomy Scores

Locomotion: 3

Manipulation: 4

Fleet: 2

This system scores high on all ends. The locomotion aspect does not get the full points because it is mainly driven within a fixed and environment, and is greatly dependant on a system of rails or external guiding systems. The manipulation, however, is done in a highly automated way, but lacks information on how well the system knows the plants. Fleet operation has been taken into account, but is not yet fully developed.



IRONOX

The last type of farming activity is a completely new one, and is heavily dependent on robotics. Indoor farming is gaining popularity in combination with hydroponics. Although these systems are not applicable yet for any type of produce, leafy vegetables thrive and production in this way greatly increases yield, while lowering emissions and energy consumption.

Autonomy Scores

Locomotion: 4

Manipulation: 3

Fleet: 2

The system of robotic trollies moves around the trays of plants to the required workstation for inspections and actuations, which grants this concept the high locomotion and manipulation scores. As for fleet operation, multiple trollies work independently, but it is unsure how well they are aware of each other.



TECHNOFARM

The second indoor farming system focusses on vertical farming principles, to drastically increase the capacity of a square meter. Also relying on high-tech measurement and monitoring systems to cater to every need of the plants. Also this system relies on aquaponics and therefore only applied on leafy vegetables.

Autonomy Scores

Locomotion: -

Manipulation: 3

Fleet: 1

Due to less information availability, this system could not be valued as well as others. Nevertheless, the high technological necessity of such monitoring systems gives it the benefit of the doubt with regards to manipulation. The locomotion aspect is unknown and also no fleet operation is mentioned.





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