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Whitepaper autonomous growing

What is it and how can you benefit?

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What is autonomous growing?

In today's world growing crops in a greenhouse is a complex affair. A grower must make several decisions to optimize his crop growth in the greenhouse while considering all the aspects that can impact plant growth like light, humidity, CO2, the outside weather, etc. Besides this, pests and diseases are a continues lurking enemy and must be controlled at all times. This is a complex task, and the grower should always be on top of his game. However, these talented growers are becoming scarce while worldwide the horticulture sector is rapidly growing.

Over the past years major breakthroughs in digital technologies like Artificial intelligence (AI), robotics, Unmanned Aerial Vehicles (drones) etc., allowed for new innovations in the horticulture sector. One of these innovations is autonomous growing, which as the name suggest, is the growing of plants without human intervention. Autonomous growing uses AI algorithms in combination with greenhouse climate, irrigation, and crop growth control to grow crops without human intervention (Hemming et al., 2019).

The autonomous greenhouse

To make a greenhouse autonomous, you need to be able to measure and control everything from a distance. Which means that every aspect of the plant growth must be monitored and controlled. In figure 1 below you can see an example of the first autonomous greenhouse challenge. The teams were able to control a small greenhouse which was equipped with standard actuators, pipe heating systems, roof ventilation, movable light screens, artificial lightning systems, Rockwool, irrigation dripping system, sensors etc. (Hemming et al., 2019). With this long list of equipment, the question arises; what does a grower need to grow crops autonomously?

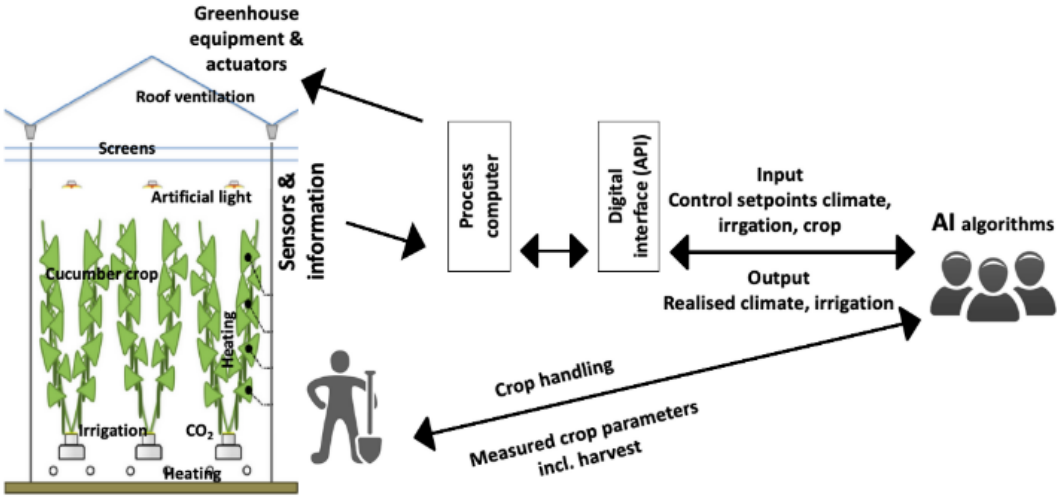

Figure 1 Scheme of data exchange in the first autonomous greenhouse challenge (Hemming et al., 2019)

Why go autonomous

You might be wondering after reading all this, why would I even go through all this trouble as my current method of growing is working perfectly fine. Well, there are a few challenges that threaten the current way of working. We foresee three reasons for you to go autonomous; increase business resilience, manage complexity, and accelerate business growth.

1. **Increase business resilience**

First, there is a worldwide shortage of high-skilled greenhouse labour (Hemming et al., 2020). This shortage can severely impact the continuity of the greenhouse company as growers are vital in the cultivation process. Autonomous growing can both be used to support growers by giving them more tools which enables them to oversee more hectares of crops or by substituting growers as one moves to a fully autonomous growing system.

2. **Manage complexity**

Another trend in the horticultural sector is the scaling-up of greenhouse companies. In the Netherlands for example, the average size of a greenhouse company has increased by 400% between 1997 and 2017 (CBS, 2018). The rapid scaling-up of greenhouse companies also increases the complexity. Overseeing this increased complexity could be a reason to start looking at autonomous growing as this is an opportunity to move towards a centralized decision-making system.

3. **Accelerate business growth**

Finally, if your greenhouse company has big growth ambition both in your home country and abroad, autonomous growing can accelerate this growth. A big advance of autonomous growing is that it is very scalable. Thus, expanding your existing greenhouses or building completely new greenhouses is simplified.

Necessary technologies

The above-mentioned list of equipment and technologies can essentially be subdivided into three main categories: sensing and monitoring, analysing and decision making and intervention. Each of these processes will be discussed below in more detail.

Sensing and monitoring

The first step in autonomous growing is to gather all relevant data that is needed to make accurate decisions. Data on the greenhouse climate like temperature, CO2, solar radiation, humidity etc., which can be gathered by sensors or a climate computer that is currently present in all high-tech greenhouses. Second, data related to the plant itself like plant size, leaf colour, stem thickness, number of flowers etc. This data can be gathers through sensors or cameras. Third, data related to the outside weather, which can be gathered through external sources like local weather stations. And finally, in a more advanced stage of autonomous growing, external data sources like real-time market and price information can be included. The algorithm could for example consider that certain weeks of the year prices are higher and push the plants to higher yields in those weeks and make up it in weeks with lower prices.

As can be seen in the autonomous greenhouse challenge, plant data is gathered with the help of sensors and cameras. However, commercial greenhouses are much larger than the small test compartments used in the autonomous greenhouse challenges. For example, for the 96 m2 test compartment already several cameras were used to monitor a variety of characteristics like plant

health, number of fruits, ripening of the fruits etc. (Hemming et al., 2020). This, however, gets very costly if you want to scale up this compartment to commercial size, as you might need hundreds of cameras and sensors to monitor every corner of your greenhouse. This leads us to the following challenge; how do we map the entire greenhouse without having to invest a fortune?

Currently several solutions are being investigated and developed to tackle this issue. The main idea among these solutions is that instead of having a lot of static cameras/sensor in the greenhouse, you attach them to a device which is dynamic. This dynamic device can then visualise and scan the entire greenhouse for different purposes. These vision-based systems will become the eyes in the greenhouse. Where currently human eyes monitor the growth, health status and disease pressure. In an autonomous production process, dynamic systems will perform this task. The following solutions are being researched for their applicability with some solutions already being applied in greenhouses today:

Drones equipped with cameras and sensors can monitor rows of crops on a frequent time routine, making them ideal for the gathering of crop related data (Robbins, 2018). The advantages of drones are there relatively low costs and the fact that they are very dynamic making it possible to monitor the crop from a variety of angles. However, the limited battery life and the turbulence produced by the rotors are challenges that remain present. A system which automatically changes the empty battery with a charged one is currently investigated as well as reducing the drone's weight to limit the downward turbulence and thrust. This is what we, as Corvus Drones, try to develop.

Vehicles which can autonomously drive through the rows of the crops are also investigated for their applications potential. Vehicles are somewhat more static compared to drones as they can only scan and monitor the path he is driving, he might for example be unable to see the canopy of tomato crops. However, a big advantage of vehicles is that battery life and camera/sensor weight is not much of a problem. An example is the Plantalyzer developed by Hortikey.

Rail system are the third system we see as a potential candidate to gather crop related data. The cameras and sensors are equipped on a device which is guided through the greenhouse on a system of rails. An example is LUNA from the company IUNU, who attaches cameras to a rail system in the greenhouse.

Figure 2 Corvus' autonomous drone, Hortikey's Plantalyzer and IUNU's LUNA

Intervention

Okay, so we now know what data will be necessary and how we can collect this, but how do we then influence these factors to optimize plant growth? This is where the actuators come into play. Actuators can control heating, ventilation, light, CO2-, water and nutrient supply, etc. In other words, they can control everything that influences the greenhouse climate and plant growth.

Analysis and decision making

The combination of the variety of data streams and the different actuators which can influence the greenhouse climate and the crop growth should now be combined in one unified system which is able to oversee all the data streams and put in place optimal set points for every single variable influencing the crop, let us call this the greenhouse management system. Currently the growers' brain is the greenhouse management system, he determines the set points in the climate computer, monitors the crop status/health and searches for infestations of insects or diseases. However, when growing autonomous, this will be done on a computer system which uses Artificial Intelligence to analyse the data sources and based on the cultivation strategy influence the actuators in such a way that optimal growth is achieved. Thus, what currently happens in the brain of the grower will be mimicked by a computer. The great advantage of this is that a computer is objective, can store and remember more data and is able to oversee thousands of set points at the same time.

The switch from human to machine based decision-making is of course not done overnight. It is a slow process of continues improvement and where the machinery based decision making will increasingly be able to compete with human decision making. In figure 3 below this process is presented, where human input in the decision making declines, as the value that can be extracted from the data increases. Essentially four stages of data analytics are presented.

1. **Descriptive** analytics, data is basic and only analysed to a limited extend, for example a map which shows temperature differences in the greenhouse.
2. **Diagnostic** analytics, the analytics also looks for relationships among the data, for example an increase temperature lead to a higher plant density.
3. **Predictive** analysis, the data is thoroughly analysed and used to predict what is going to happen. For example in 3 weeks we expect 50 tonnes of tomato harvest.
4. **Prescriptive** analytics, the final stage in which the analytics system is used to make (decision support) or take (decision automation) recommended actions. For example, plant growth is behind schedule therefore increase temperatures by +2°C and increase light intensity. Either as an advice to the grower or the decision is taken by the system.

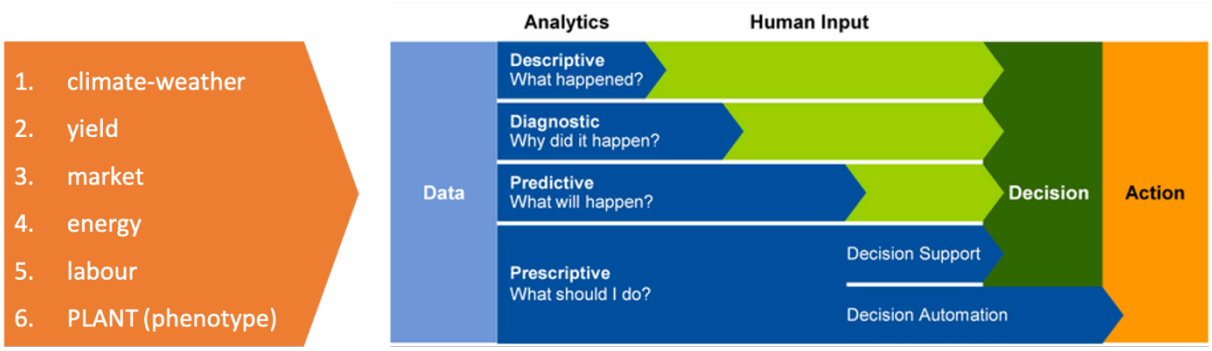

Figure 3 Levels of data analytics

The importance of a cultivation strategy

In figure 4, an example is given of the crop growth across time. The green line is the growth of the crop according to the predetermined cultivation strategy. The orange line is the actual growth, where the greenhouse management system is continuously trying to stay as close as possible to the green line. At the start of the growing season, the vision system identifies that the crop is a bit behind schedule and sends the feedback to the management system. The management system considers the weather of the coming weeks and decides to boost the crop growth by changing one of the many actuators. The weather, as unpredictable as it is, changed after the decision was made and the crop grew faster than was planned. The management system identifies this and slows the growth of the crop down again while at the same time saving his 'mistake'. The crop continues to grow, and you see a stabilizing effect where the crop growth is deviates less and less from the cultivation strategy.

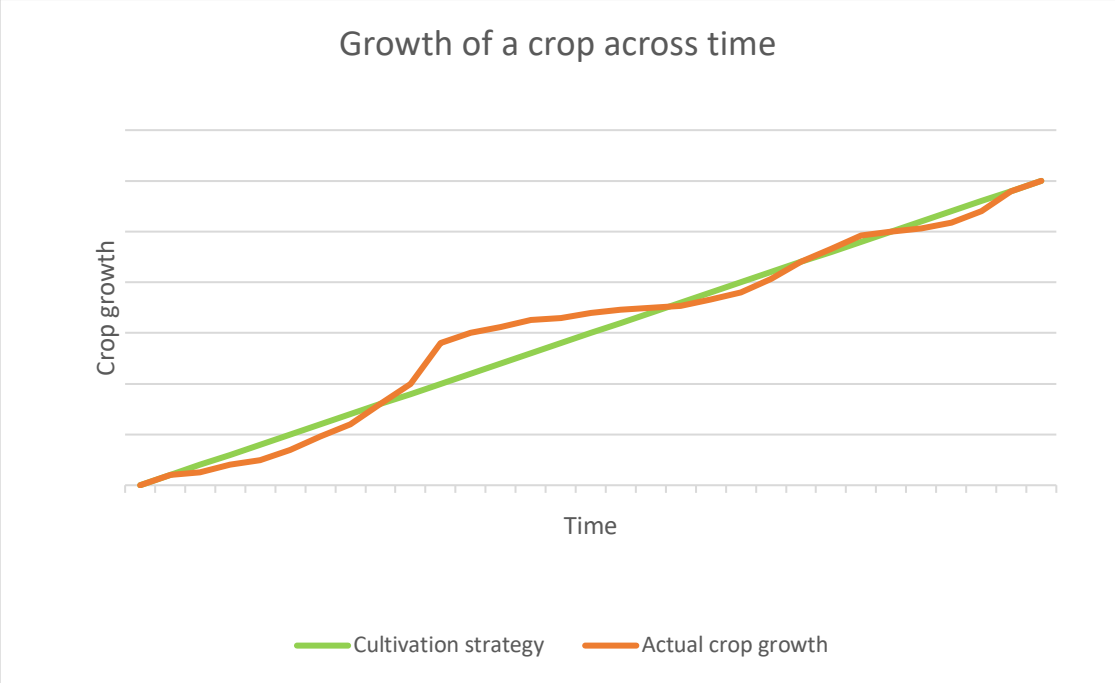

Figure 4 Example of crop growth across time

Tips & tricks

So hopefully we were able to provide you with a good idea on what autonomous growing is, how you can benefit from it and what is necessary for an autonomous greenhouse. Finally we would like to give you some tips & tricks which we believe are important when you initiate autonomous growing.

First, We believe that **a well-established cultivation strategy** is very important. When you increasingly give the analytical part of the system more control, it will increasingly need to know based on 'what' it should make its decisions. While, currently you might have this strategy in your mind, autonomous growing cannot read minds (yet). Therefore, the system will need to know which strategy it should follow.

Second, finding partners which offer the right technology and match with your vision can be hard, especially if there are many technology providers offering similar solutions. We believe that finding the right partners is important with a technology which has such a high impact on you company.

Third, the ‘Autonomous Greenhouse Challenge’ organized by Wageningen University & Research can serve as a great example. In 2021/2022 it is organized for the third time and it can give you insights into what technology is necessary, what challenges are faced when growing autonomous, etc.

Finally, we have put all this information in a 5 step-plan which should get you on the right direction!