Smart Farming: Weed Elimination with 5G Autonomous Robots

Report produced by GSMA in partnership with KPN

FEBRUARY 2020

Introduction

This case study describes how KPN and ecosystem partners have developed an IoT solution to automate and optimise the elimination of unwanted potato plants from fields of sugar beet, a problem that farmers in the Netherlands have needed to solve for many years. The proof of concept is set in a 5G test field and uses robots, deep learning, and a cloud based edge solution to identify and destroy problematic potato plants. **The project is currently achieving an accuracy of 95 per cent and able to cover one third of a hectare per hour which far exceeds the speed of manual workers.** The results show significant promise to the agricultural industry and KPN, along with the project partners, and they have identified opportunities for further improvements in the accuracy and efficiency of this precision farming solution. This proof of concept is a compelling example of intelligent connectivity in action applying 5G, IoT robotics and AI hosted on a smart edge platform.

KPN is focusing its 5G activities towards specific vertical industries; autonomous vehicles, Industry 4.0 and AgriFood. The Netherlands is the world's second largest exporter of food, measured by value.[1] In 2019, 94.5 billion euros of vegetables, fruit, flowers, meat and dairy products were exported abroad. That is 4.6 per cent more than in 2018 and the highest export value for the Netherlands ever.[2] The Government of the Netherlands attributes 17.5 per cent of total Dutch exports to agriculture.[3] KPN expect the innovation and evolution of mobile networks to deliver improvements in the efficiency, sustainability and autonomy of the sector.

To achieve these improvements, KPN has established a 5G field lab in Valthermond, Netherlands, together with partners Wageningen University and Research (WUR) and Huawei. In this field lab, multiple pre-5G and 5G technologies are tested and evaluated by means of several proof of concepts. These proof of concepts are developed in collaboration with partners from the agriculture, mobile and technology sectors to identify the most important needs and demands of farmers and businesses within the agricultural value chain.

This case study is an example of how the convergence of new technologies, together with the benefits of a 5G network, provides a new environment for the development of ground breaking IoT solutions for new and existing problems.

1 https://www.nationalgeographic.com/magazine/2017/09/holland-agriculture-sustainable-farming/
2 https://nos.nl/artikel/2318946-exportrecord-voor-nederlandse-landbouw-vooral-veel-bloemen-en-vlees.html
3 https://www.government.nl/topics/agriculture/agriculture-and-horticulture

The Problem with Volunteer Potatoes

The specific use case concerns potato tubers that remain in the ground following the potato harvest. Surviving mild winters, leftover tubers grow into unwanted potato plants in the crop that follows potatoes, in this case sugar beet. The term for a plant that grows on its own, rather than being deliberately planted, is a "volunteer" plant. Volunteer potatoes can cause problems by increasing soil-borne disease such as potato cyst nematodes and introducing pests such as phytophthora (potato blight). The elimination of volunteer potato plants and tubers is required by Dutch law to prevent these negative effects. Potato plants also grow more quickly than sugar beet plants, blocking the light from reaching the sugar beets and causing a reduction in the absorption of important nutrients by the sugar beets, negatively affecting growth.

The most effective method of removal is through the manual application of glyphosate to the individual volunteer plants. This can take up to 40-60 hours/hectare*, costing an estimated 320-480 euros per hectare[4], which is economically unattractive for the farmer. There is also a lack of workers that want to perform this type of work because it is extremely repetitive and it can be unpleasant to work in the field during a cold spring or hot summer.

Figure 1: A Sugar Beet Field with Volunteer Potatoes

Figure 2: A Sugar Beet Field with a Severe Volunteer Potato problem

[4] Based on the Netherlands national minimum wage 8.04 euros (38hour week).
* Over two or three applications per year.

Other chemical methods are available to control the potato haulm (stalk); however, they only suppress the unwanted plants temporarily, and the problem remains. Mechanical means ensure potato haulm removal, but do not take out the tubers and this must be done up to 10 times before tuber reserves are exhausted. All these solutions are not sustainable for the farmers.

Finding a way to automate the detection and elimination of volunteer potatoes will provide the basis for an economically suitable solution for famers, but also address the United Nations Sustainable Development Goals (SDGs)[5] which focuses on the minimisation of chemicals, in this case herbicides, used on the land. See the "Sound management of chemicals and waste" section for more about the relevance of this project to the SDGs.

Sound management of chemicals and waste

The 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) were adopted by the General Assembly of the United Nations in September 2015. Sound management of chemicals and waste (SMCW) is a specific target under SDG 12 on Responsible Consumption and Production. It is also referred to under SDG 3 on Good Health and Well-being and SDG 6 on Clean Water and Sanitation. However, given that chemicals and waste affect almost all aspects of development, SMCW is relevant for, and supports the implementation of many other, if not all, SDGs.

Source:

https://unitar.org/sustainable-development-goals/planet/our-portfolio/sdgs-chemicals-and-waste

[5] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

The Solution

The project is based on a Robotti robot which is a diesel powered autonomous tool carrier from Danish development company, Agrointelli[6]. The robot is fitted with cameras, to capture images of the plants in the ground, and precision sprayers connected to a tank of herbicide and the control computer.

The image data captured by the cameras is sent from the robot to a cloud based edge[7] computing server in The Hague via a 5G connection. The cloud edge server hosts a deep learning algorithm, which is a state-of-the-art machine learning algorithm, trained to recognise sugar beet and potato plants in images. The training of a deep learning algorithm can be compared to training the human brain: through repetition, by exposure to a large volume of images. In this example, the algorithm has been trained using approximately 6000 images of sugar beet and potato plants, captured at different growing points and across multiple growing seasons, enabling the machine to attempt to classify potato plants from live images taken in the 5G field.

Once the classification is done on the cloud edge server, a reply is sent to the robot. If the reply confirms that a plant image has been classified as a potato plant, the robot invokes the appropriate sprayer to apply glyphosate to the identified plant. The full cycle takes approximately 250 milliseconds which comprises of 20-25 milliseconds for the communication from the vehicle to the central computer and back again and 200-230 milliseconds for the cloud application to process and analyse the images.

The use of edge computing enables the camera data to be offloaded and eliminates the need for a Graphics Processing Unit (GPU) at the robot. The practice of locating the GPU in a cloud edge server, processing data and returning a task to a moving robot in "real-time" is unique in the market. The required bandwidth to achieve this quickly enough, around 120Mbps upstream during peak moments, is not feasible without 5G, and the KPN 5G field lab has provided a test environment to demonstrate this possibility.

Figure 3: A Sugar Beet Field with Volunteer Potatoes

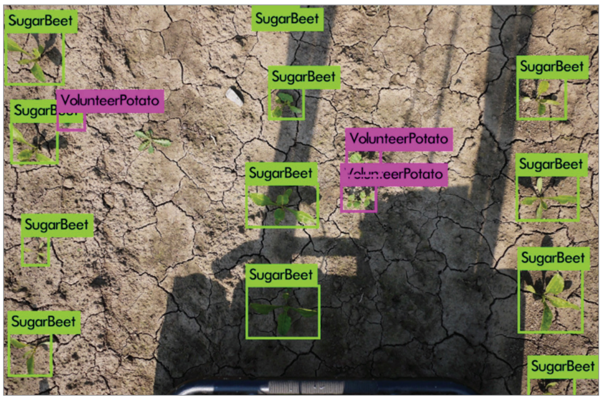


Figure 4: The field with Sugar Beet and Volunteer Potatoes identified using detection software

[6] http://agrointelli.com/robotti-diesel.html#rob.diesel

[7] *Cloud based edge* means offering services that are typically available in cloud environments, but deployed nearer the edge of the network to offer particular benefits including a reduction of network latency and long range bandwidth reduction.

Doing this in "real-time" enables the robot to work continuously and autonomously, without the need of extensive processing power on the robot itself. Removing the need for a GPU on the robot has a number of direct benefits:

- The amount of vulnerable hardware, which can be exposed to rain, humidity and temperature fluctuations or temperature extremes, is reduced and the GPU is now in an environment where conditions are perfect for optimal utilisation of the hardware e.g. forced air cooling.
- **The complexity is reduced and the cost of the robot decreases by approximately 5-10 per cent**. GPUs can be very costly and have additional (costly) hardware requirements e.g. high DC power regulators.
- A reduction in the physical weight of the robot which in turn reduces fuel demand and soil impact.
- No large electrical power consumption by GPUs means longer operating time, especially on electric robots.
- There is an opportunity to optimise GPU utilisation across the year. GPUs in the cloud edge can easily be used for other applications. The farmer has a limited period of between two to three months to remove volunteer potatoes so if all of the computing hardware was located on the robot there would be limited opportunity to repurpose the GPU to solve other problems throughout the year.

Figure 5: Autonomous Robot showing the tank containing herbicide above and 29 spray nozzles at the base near the ground.

Identifying Potato Plants with Deep Learning

Koen van Boheemen, MSc Student at Wageningen University explains how **Deep Learning was applied to the potato problem.** This describes the first phase of the algorithm which has since been **trained using approximately 6000 images:**

"The desire to accurately recognise plants in an agricultural field has been pursued for many years. With the introduction of ground-breaking deep learning technologies, we now have the tool we need to do the job. Deep learning algorithms can be trained to recognise objects by providing (both positive and negative) examples of the object to be recognised. Starting with around 300 images recorded in the first year, a first version of the algorithm was trained over the winter months. Using 200 images which the algorithm had never 'seen' before, the algorithm was tested and performance was promising. After a long winter we entered the sugar beet field full of confidence, only to be disappointed.

For us, the sugar beet looked exactly the same as in the previous year but not so for the algorithm. However, by adding 100 images from the current year, we were able to return to original performance. This shows that situations which for us are the same can be very different for a computer. Explicit differences such as growth stage are as important as implicit differences which we don't even think about.

By having the algorithm store images where a decision was uncertain in a separate folder and returning these images with manually added labels and by adding extra training-data from other datasets, we could quickly improve the performance to its current level. We are now waiting for next spring to repeat this trick for even more."

Figure 6: The autonomous 5G robot solution, developed by KPN and Wageningen University and Research (WUR)

Figure 7: The autonomous robot IoT solution in a sugar beet field

Results

KPN, together with Wageningen University and Research (WUR), have developed an IoT proof of concept which combines the application of 5G connected robots, Artificial Intelligence (deep learning) and cloud based edge processing power to address large scale outdoor crop management.

The critical success factor for the project is measured by determining the effective control of the volunteer potato plants and the capacity of the robot (amount of hectares per hour).

An experiment to measure the accuracy, using water rather than herbicide, showed that **95 per cent of the volunteer potatoes were successfully identified and sprayed**. This is approximately equivalent to human performance. However, approximately 4 per cent of the sugar beet was sprayed in error and it is thought that this was due to the setup of the spraying nozzles and not necessarily because the sugar beet was identified as potato. The spraying nozzles, mounted at a 10cm distance, would sometimes hit a sugar beet while spraying a potato. The precision of the spray boom (actuator)[8] is discussed in the *Next Steps* on page 8. Although a human worker may also spray herbicide on sugar beet plants in error, they are able to rectify this by removing the affected leaf. While this may negatively influence the plant slightly, removing the leaf means the plant will not die from the chemical. The robot cannot do this.

The project team working on the proof of concept observed the total cycle time, depicted in Figure 6, to be around 250 milliseconds. This sets the rate for how many images can be acquired and processed to 4fps (frames per second). There are four cameras present on the robot to cover the 3.0m working width, and each camera captures four images per second totalling 16 images per second across the width of the robot.

While the robot is capable of moving at up to 5 km/h, the driving speed in this proof of concept was limited to 3.5 km/h (about 1 m/s) due to the processing time and distance between cameras and spraying boom. This limitation will be addressed in a future development of the project and described in the *Next Steps* on page 8. However, even at the restricted speed, **the robot was able to spray 95 per cent of the potato plants in the beet field at 3300m²/h.[9] This is approximately 3 hours per hectare, repeated 2 or 3 times a season, for the IoT solution compared to 20 hours per hectare repeated 2 or 3 times a season, with manual application. The robot is 6.67 times more productive than the manual worker.**

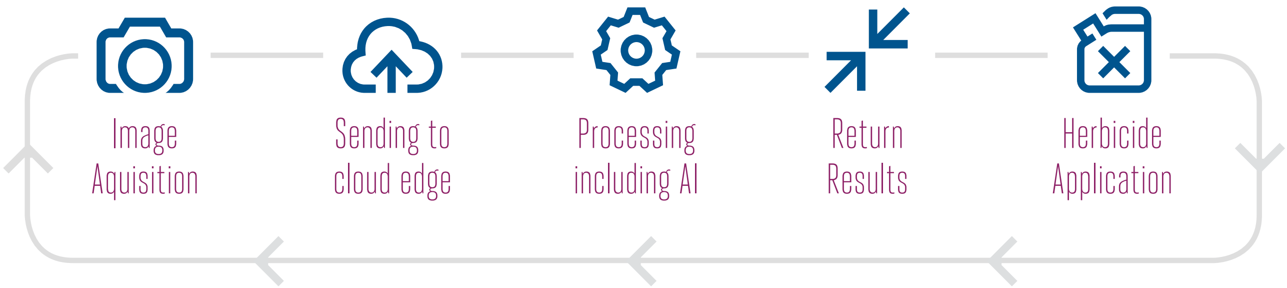


Figure 8: The process cycle from image capture to herbicide application

[8] The spray boom is the pipe with attached nozzles for distributing spray, in this case herbicide, from a tank. An actuator is a device (usually mechanical) responsible for generating a movement in a mechanism or system. https://www.sciencedirect.com/topics/engineering/actuators

[9] This takes into account turning on the headland. If the robot were to only go in one direction it would be approximately 3600m²/h

Next Steps

- Adjust the distance between the cameras and spraying boom, to account for the processing time. Improvements to the spraying boom will allow for greater precision in application, further reducing the environmental impact and the percentage of the sugar beet crop that is sprayed erroneously.
- Additionally, the project team is looking at the possibility of adapting and training the deep learning algorithm for application in crops other than sugar beet where volunteer potatoes similarly need to be controlled.
- Finally, the team is looking at the opportunity to collect more data for management decision support. This could be information about the sugar beet count, drought detection, disease detection, growth monitoring, yield estimation, and so on.

In terms of commercial development, KPN are in contact with machinery companies to roll out the service commercially. Early plans include a longer running pilot and then a commercial roll out.

For the future, KPN and WUR see a potential for this method of detecting volunteer potatoes to be applied to a solution that uses a non-chemical method of potato removal and thus contributing further to SDG12 through the minimisation of chemical use in agriculture.

Summary

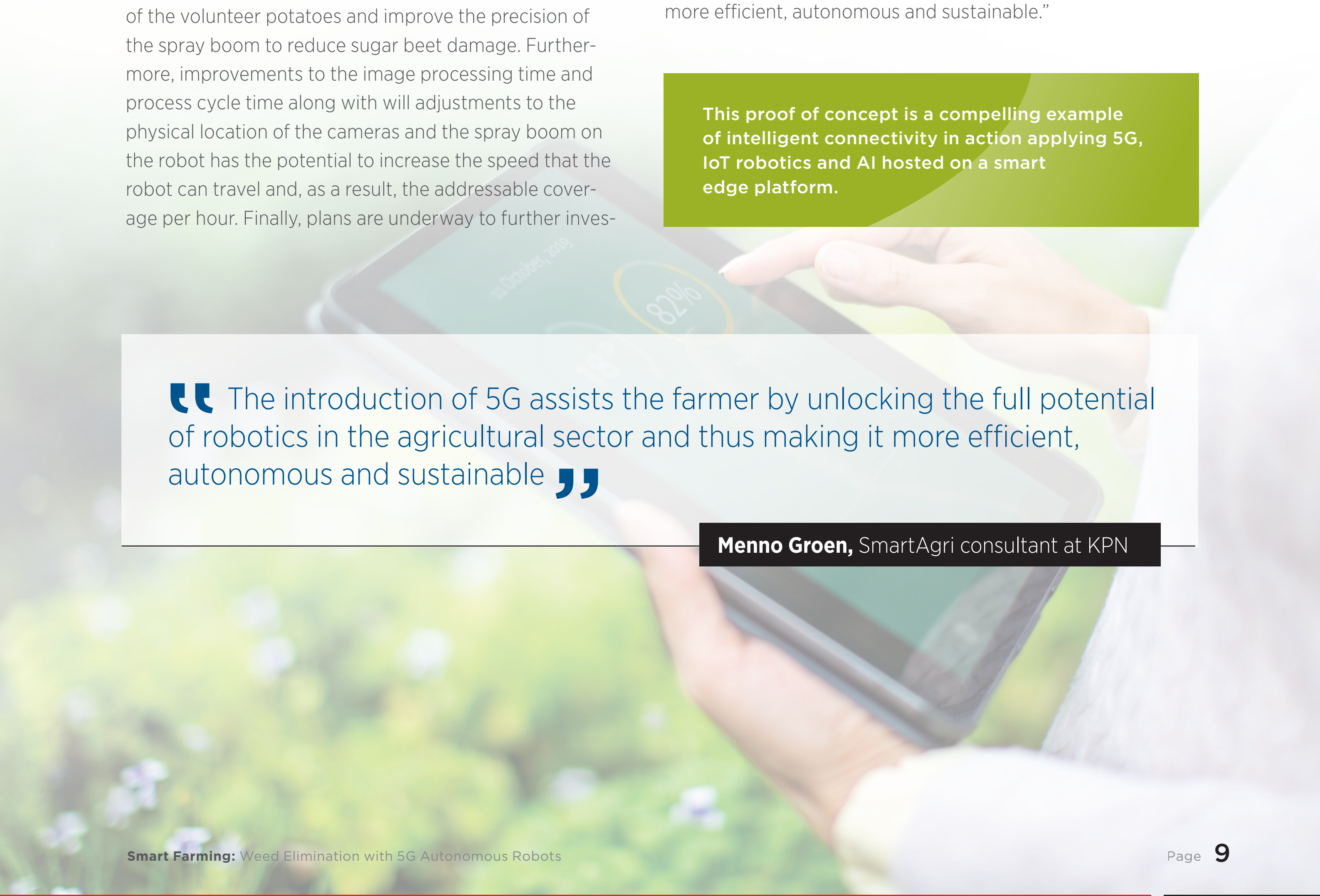
KPN together with Wageningen University and Research (WUR) and Huawei has successfully demonstrated how 5G can enable "real-time" image processing in precision farming at the 5G field lab in Valthermond, Netherlands. The project also shows how the convergence of technologies such as 5G, deep learning algorithms and edge computing can develop innovative solutions for the precision agriculture industry.

The proof of concept has demonstrated the ability to identify and spray volunteer potato plants in a sugar beet field with an accuracy of **95 per cent at a coverage of 3300m²/h (1/3rd ha per hour)**, representing a speed-up of up to **20 times a manual labourer.**

Following the success of this proof of concept, the team have the further opportunity to improve the accuracy of the deep learning algorithm to identify over 95 per cent of the volunteer potatoes and improve the precision of the spray boom to reduce sugar beet damage. Furthermore, improvements to the image processing time and process cycle time along with will adjustments to the physical location of the cameras and the spray boom on the robot has the potential to increase the speed that the robot can travel and, as a result, the addressable coverage per hour. Finally, plans are underway to further investigate and test the adaptability of the model for application in crops other than sugar beet where volunteer potatoes need to be controlled and also look at additional data that can be collected by this model to support decision management.

As KPN look towards a path for commercial rollout of this solution, Menno Groen, SmartAgri consultant observes, "The introduction of 5G assists the farmer by unlocking the full potential of robotics in the agricultural sector and thus making it more efficient, autonomous and sustainable."

This proof of concept is a compelling example of intelligent connectivity in action applying 5G, IoT robotics and AI hosted on a smart edge platform.



"The introduction of 5G assists the farmer by unlocking the full potential of robotics in the agricultural sector and thus making it more efficient, autonomous and sustainable"

Menno Groen, SmartAgri consultant at KPN

About the GSMA

The GSMA represents the interests of mobile operators worldwide, uniting more than 750 operators and nearly 400 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies, as well as organisations in adjacent industry sectors. The GSMA also produces the industry-leading MWC events held annually in Barcelona, Los Angeles and Shanghai, as well as the Mobile 360 Series of regional conferences.

For more information, please visit the GSMA corporate website at www.gsma.com.

Follow the GSMA on Twitter: @GSMA.

About the GSMA Beyond Connectivity campaign

Delivering seamless IoT connectivity has been a crucial element in helping operators to launch new services such as low power wide area (LPWA) networks, using NB-IoT and LTE-M technologies and create added value and sustainable growth. Now leading IoT operators are building on this and their reputation as trusted industry partners by delivering value added services beyond connectivity.

These end-to-end solutions include services across big data, machine learning, analytics, edge computing and distributed ledger technologies. They are delivering substantial benefits to customers such as increased productivity, reduced costs and automated business processes as well as driving innovative new products and services, new lines of business and new business models. Services beyond connectivity are transforming businesses and industries.

www.gsma.com/BeyondConnectivity

About KPN

KPN is a leading telecommunications and IT provider and market leader in the Netherlands. With fixed and mobile networks for telephony, data and television KPN serves customers at home and abroad. KPN focuses on both private customers and business users, from small to large. In addition, they offer telecom providers access to their widespread networks.

More information can be found on www.kpn.com and www.kpn.com/smartfarming/

About Wageningen University and Research

Wageningen University & Research is a combined University and research institute in the Netherlands focussing on the green domain. Domains covered by Wageningen education and research are constantly expanding. Originally an agricultural university, Wageningen currently is world-renowned for education and research in food, economics, social sciences and agriculture. With a large team working on agricultural technology, artificial intelligence and robotics, Wageningen is hoping to contribute to the farming systems of tomorrow.

https://www.wur.nl/en/About-Wageningen.htm

For more information please visit:
www.gsma.com/IoT

GSMA HEAD OFFICE
Floor 2
The Walbrook Building
25 Walbrook
London EC4N 8AF
United Kingdom
Tel: +44 (0)20 7356 0600
Fax: +44 (0)20 7356 0601