Automation

Autonomous vineyard robots and tractors

In keeping with the theme of our WineEng 2020 Forum and Trade Review, we move to the vineyard to learn how automation can potentially enhance operations there. Autonomous robots and tractors are likely to be a key feature of agriculture in the future. In this article, AWRI Senior Engineer **Simon Nordestgaard** reviews recent developments.

Introduction

In France, there is significant activity in agricultural robotics. Multiple companies are developing machines, a national association to represent agricultural robotics has been formed (RobAgri), and a conference dedicated to agricultural robotics is being held each year (FIRA). In 2018 Le Comité Champagne even launched a robotics competition to develop vineyard robots for their region. At the 2019 SITEVI equipment trade show in Montpellier, three robots aimed at vineyards were displayed: Bakus by Vitibot, TED by Naïo, and Trektor by SITIA. The primary driver of the development of these machines for French viticulture is pressure to reduce the use of herbicide and the much higher costs of under-vine weed management using cultivation if that process is not better automated. Secondary drivers are a cost reduction in other vineyard operations and worker health and safety.

Over the row

Bakus (Figure 1), TED (Figure 2), and Trektor (Figure 3) are all designed for 'over the row' operation. This allows for good alignment of under-vine cultivation tools around the vines, irrespective of row width. However, the width of the Trektor is adjustable and SITIA proposes that it may sometimes also be used in the mid-row (Figure 3b). Larger versions of some of these machines may be needed if they are to be used over the row in some Australian vineyards.

Robot guidance

The vineyard robots all employ high accuracy satellite positioning (see box at the end of the article on satellite positioning). The vineyard needs to be mapped before the robots can be used – by drone survey if it was not already surveyed during planting. The route is set primarily based on this survey, with other sensors then used mainly for 3D guidance and obstacle detection (see box at the end of the article on sensor technologies). The robots are typically placed in the vineyard and then operate as programmed. Notification messages are sent to the user as required to advise of issues such as stoppages or low battery level warnings.

Power

A major difference between many autonomous agricultural robots and traditional tractors is that robots are often electrically powered. Electric power is desirable because it can facilitate the use of renewable energy and because electric motors are generally more energy efficient and can be controlled more precisely. However, batteries are expensive and not very energy dense. Batteries of practical sizes can be depleted quickly in demanding applications.

The Vitibot Bakus (2.5 tonnes with tools) is entirely electric. It has an 80 kWh battery that allows 10 hours of operation. An earlier prototype (Figure 4) featured solar photovoltaic panels; however, these have been removed in the more recent models (Figure 1) because they were not generating much electricity and without them it is easier to adapt the machine's design to different vine heights. As an order of magnitude estimate, if it is assumed that the panel area was 6m^2 and that the panels could generate 0.2 kW/m^2, in an hour the panels would only generate 1.2 kWh while the machine consumes around 8 kWh (80 kWh/10h).

Figure 1. Vitibot Bakus - available in two different sizes to accommodate different vine heights: (a) running in a vineyard, and on a different occasion, (b) underneath view showing one side of thevineyard floor management tools fitted to the robot - a serrated disc, electrically actuated inter-vine cultivator with feeler, and an electric rotary mid-row mower.

Figure 2. Naïo TED - with under-vine cultivation implements: (a) on display at SITEVI, and (b) in a vineyard

Figure 3. SITIA Trektor – comes in three versions with different adjustable widths: (a) at SITEVI in an over the row configuration, and (b) in a vineyard between rows

Figure 4. Early Vitibot Bakus prototype, c. 2018, with solar photovoltaic panels

It is therefore understandable that these design changes were made. The robot can still be renewably powered – a larger area of solar panels could be installed elsewhere and that power used to charge the vehicle. The Naïo TED (800 kg) is also fully electric with the battery providing 8 hours of operation.

Eight to ten hours of operation before these vehicles need to be manually recharged is quite good, but to really take advantage of a vehicle being autonomous, it would ideally be run almost constantly, only stopping to charge itself when necessary. Domestic grade autonomous lawnmowers (e.g. Figure 5) can run in this manner; they automatically return to their charging station whenever needed. Despite the domestic lawnmower battery capacity only allowing quite a short working time, it is very autonomous because of its ability to recharge automatically when needed. This sort of solution could likely also be developed for the Vitibot Bakus or Naïo TED. The challenge with a vineyard compared with a home lawn is that there needs to be a charging point not too far away and the robot needs to be able to get there without using public roads. This should be consideration in the design of new vineyards.

Not all agricultural robots are electric. For example, Agrointelli has sold more than 20 diesel-powered Robotti machines to arable farmers (Figure 6). One of its two Kubota diesel engines provides propulsion and the other provides power take-off (PTO) and hydraulics for implements. Interestingly, Agrointelli started its robot development using electric motors, but ended up switching to diesel motors. Apart from needing a propulsion system that could drag up to 3 m wide implements for long periods of time, it found that farmers really liked the use of diesel engines and hydraulics in their robot because it was something that they were already familiar with (Jæger 2017).

A hybrid diesel-electric propulsion system is being used in the SITIA Trektor (2.7 tonnes, Figure 3) as well as in another vineyard robot being developed by Agreenculture (Figure 7) that is to be launched commercially in 2021. The Agreenculture Céol can run for around 20 hours using the diesel engine and 1 hour when relying on the battery alone.▸

Figure 5. Domestic autonomous lawnmower at its charging station (if the battery is getting low, the lawnmower returns to charge automatically and then goes back to work when the battery is charged)

Figure 6. Agrointelli Robotti

Figure 7. Agreenculture Céol (Agreenculture is also developing a separate robot in collaboration with Pellenc for Champagne as part of that region's robot competition)

Custom or standard implements

Vitibot has developed its own fully electric vineyard floor management tools for the Bakus (Figure 1b). An integrated recycle sprayer will be released later this year (Figure 8), followed later by further custom electric tools. Other vineyard robot manufacturers are taking a different approach. SITIA and Agreenculture are focused on being able to work with existing implements (Agrointelli has also taken this approach with its robot, Figure 6). The Naïo TED currently only works with unpowered implements; however, Naïo is now working on a new platform which will allow more flexibility in the tools that can be used.

The SITIA Trektor has both a 25 L/min hydraulic oil supply and a 15 kW electricity supply for implements. The Agreenculture Céol currently only has an electrical supply for implements but an external hydraulic pump can be fitted (shown in Figure 7). The 25 L/min hydraulic oil supply specified for the SITIA Trektor is likely enough to supply the hydraulics on under-vine cultivation implements or to drive some other single-row equipment, but would not be enough for larger equipment. However, if it is able to run autonomously day and night, the need to run quite as fast or to treat multiple rows simultaneously might not be quite as important as it is when a person is driving a tractor.

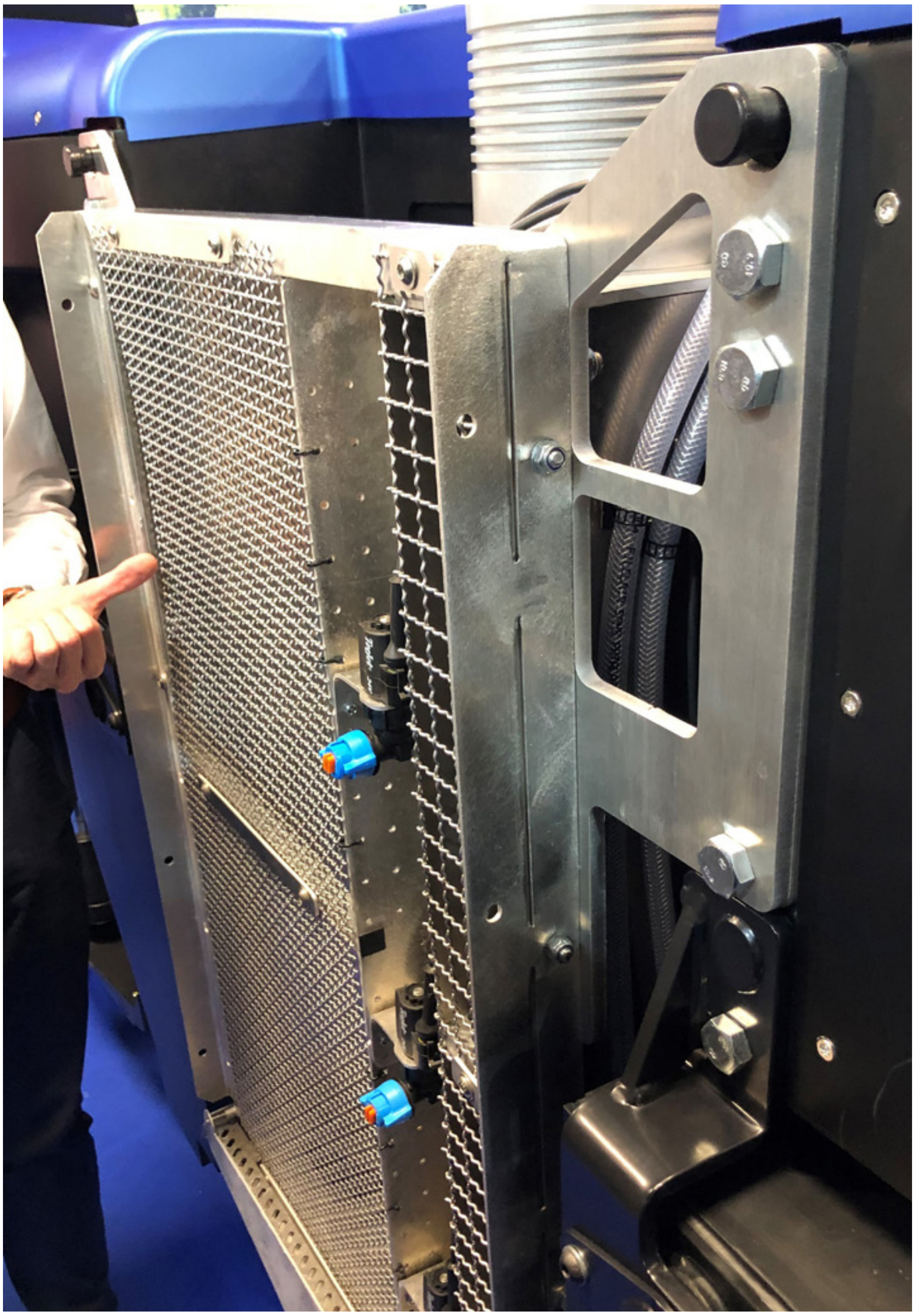

Figure 8. Prototype recycle sprayer installed on Vitibot Bakus at SITEVI in 2019 (a newer version is now almost ready for deployment – 400 L of liquid is carried)

The ability of the SITIA Trektor and Agreenculture Céol to work with existing implements could make adoption of these robots easier and also take some pressure off these companies as they do not have to develop all the vineyard tools themselves in addition to building the robot. The counter-argument is that specifically designed implements such as on the Vitibot Bakus may provide a more seamless integration and prevent issues that might arise from simple implements that were designed assuming that there would be a person on a tractor in front of them to manage any malfunctions. In the case of electric robots like the Vitibot Bakus, the development of efficient electric implements should also minimise demand on the limited battery capacity.

Cost and availability of vineyard robots

The SITIA Trektor went on sale in France in 2020 and costs around A$350,000. SITIA advises that a demonstration model will be available in Australia later in 2020. The Vitibot Bakus also went on sale in France in 2020. More than ten are currently working in vineyards. The entry level machine costs around A$200,000 and the full option machine designed for steep slopes, including under-vine cultivation and mid-row mowing tools and a fast charger costs around A$300,000. Vitibot advises that it intends to sell some Bakus machines internationally in the next two years. Naïo's TED robot is not commercially available yet, but they are being used by 19 customers as part of ongoing research and development projects.

More often but slower or less

Autonomous vehicles can potentially work day and night and this presents an opportunity to do things differently. For example, the use of autonomous vehicles could allow operations to be performed with single-row equipment that is slower, or to conduct activities such as mowing mildly many times instead of severely a few times.

Gaviglio (2019) is performing some fascinating ongoing work investigating whether mowing the under-vine area at a high level very frequently has a different effect on the competition between the weeds and vines for water and nutrients, than mowing under-vine severely less often. Anecdotally, severely mowing under-vine as a weed management strategy can be risky because weeds may take water and nutrients away from the vines as they grow again. If a milder but more frequent mowing strategy turned out to avoid that, autonomous mowing could be another mechanical option for under-vine weed management that is simpler and less likely to damage vine trunks/roots than cultivation.

One of the very first autonomous vineyard robots developed was an autonomous mower. Vitirover won the Special Jury Prize at the Vinitech-Sifel trade show in 2012 and the mower has been further developed since then (Figure 9). Vitirover now has 100 of these mowers in use and are in the process of building another 200. The mowers are not currently sold directly, instead they are offered as part of a mowing service at an annual charge of around A$5,000 per hectare. The robots weigh less than 20 kg and consume very little electricity. They are therefore able to be powered by a small solar photovoltaic panel. In order to use a mowing robot for under-vine weed management, drippers and mounding in the under-vine area would need to be arranged in such a way that they do not obstruct the robot from accessing that zone. Vitirover appears to also have had some success with its mowers in areas that would be dangerous for a human operator, such as alongside train tracks and at electricity sub-stations.

Precision spraying

Many agricultural robots currently being developed perform 'green-on-green' weeding. They use machine vision and techniques that allow them to differentiate between green crops and green weeds and therefore give them an ability to weed automatically in-crop, unlike 'green-on-brown' technologies (e.g. Weedseeker) that are good for spot spraying, but cannot distinguish between plants of the same colour.

One robot employing this technology is the Ecorobotix AVO (750 kg fully loaded, Figure 10). It identifies the weed and then sprays a small amount of herbicide just on the weed. The precision spraying means a much smaller volume of liquid needs to be carried by the robot than if blanket spraying was used and the energy needed to generate the smaller volume of spray is also lower. This lower energy use is important when a battery and solar photovoltaics are being relied upon. The AVO reduces herbicide use by 90% and it carries only 120 L.

Unfortunately, precision spraying techniques seem likely to be much more applicable to the use of herbicides for weed management, than for the canopy fungicide sprays that make up the majority of spray operations in vineyards. Many canopy sprays provide a protectant effect rather than a curative treatment, and therefore it would likely be difficult to target specific features.

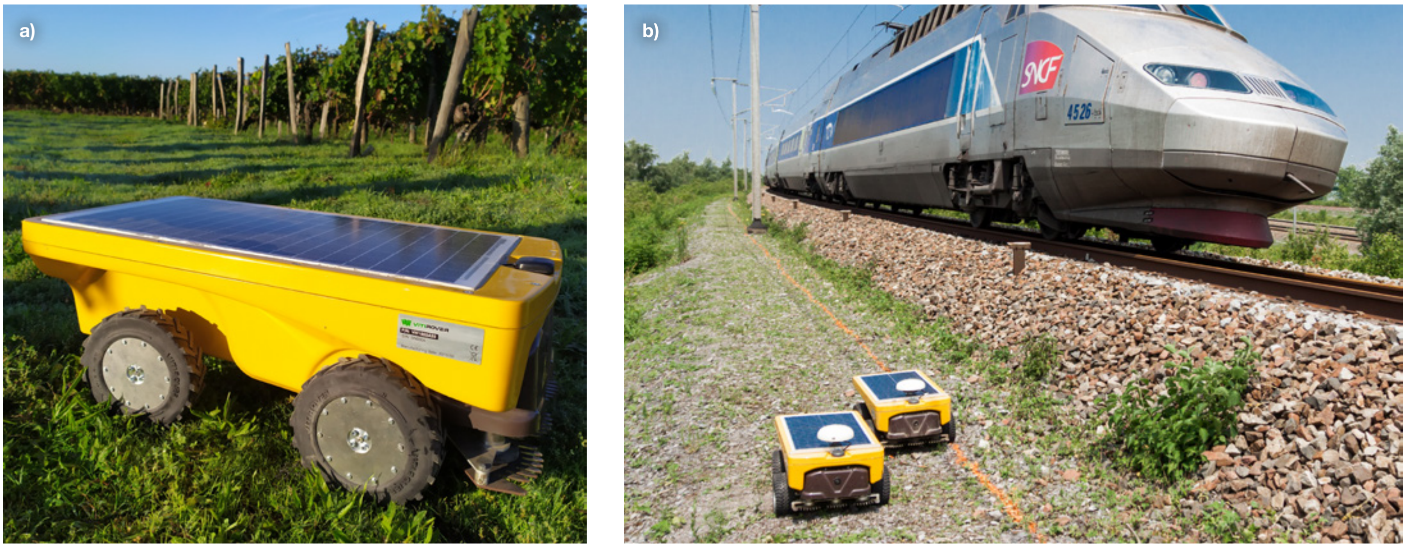

Figure 9. Vitirover mowing robot: (a) In a vineyard, and (b) alongside train tracks

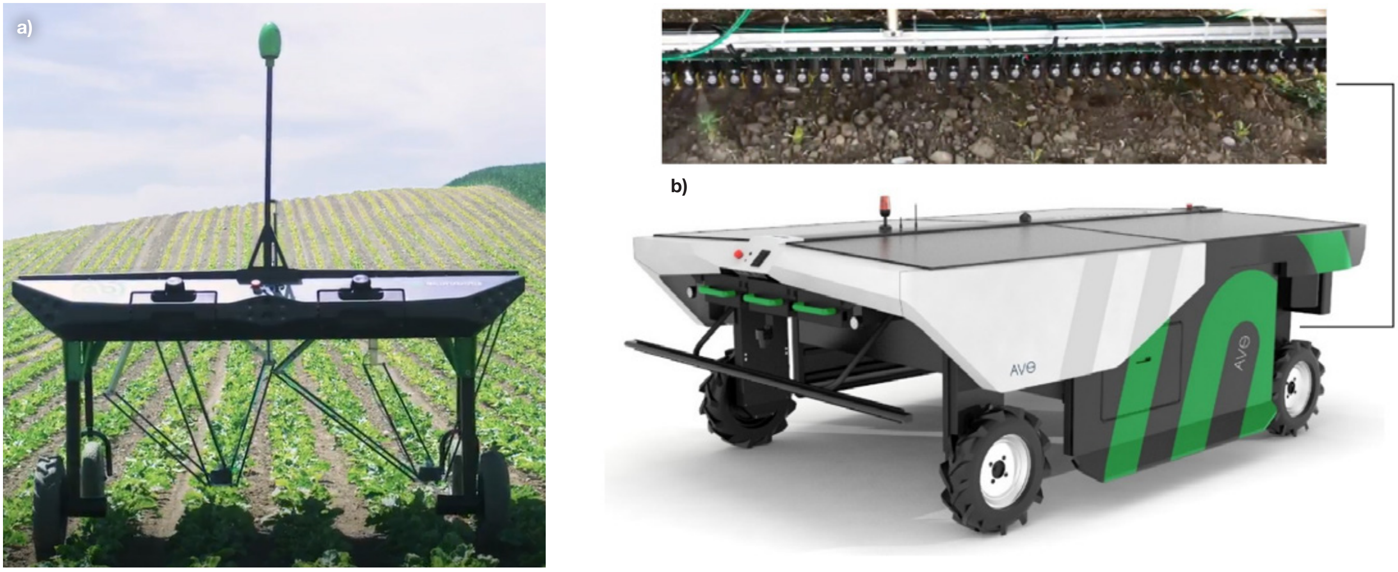

Figure 10. Ecorobotix precision weed spraying robot: (a) 2018 prototype with sprayers on delta arms that move to just above the weed and spray it, and (b) 2019 AVO version with a view of the multi-valve spray-bar underneath the robot that allows for faster operation than with delta arms

Small robots and big tractors

The difference between what is a robot and what is a tractor is a little blurry. The main points of distinction tend to be whether it is manned (like a traditional tractor) or unmanned (a robot), whether it is a general purpose vehicle that performs multiple tasks (like a traditional tractor) or is more dedicated to specific tasks (often a robot), and if it is big (like a tractor) or small (often a robot). There is a spectrum and some vehicles could fairly be referred to as either a robot or a tractor.

In broadacre farming, productivity increases have for a long time been driven by larger implements and correspondingly larger tractors to drag them around. This led to increased productivity per driver, but also soil compaction. Many proponents of small robots note that once the driver is removed, so is the need to have such big machines – one person could instead manage many smaller machines (a 'swarm'). However, it should be noted that issues with soil compaction in broadacre farming have been partly addressed by the use of controlled traffic farming where heavy machinery always drives on the same tracks and therefore only compacts a small area of soil, and/or by the use of belts instead of wheels on tractors. In vineyards it also seems likely that while soil compaction may not be ideal, it might not be such a problem as it is on broadacre farms given the smaller tractors in use.

Where an autonomous vehicle is developed for general purpose use in place of a tractor, a decision needs to be made as to whether it has a cab or not. Removing the cab likely makes the vehicle slightly cheaper, but also removes the possibility of ever being able to drive it manually. For large autonomous vehicles it seems most likely that they will retain cabs for a very long time to give the user flexibility. For the purposes of concept vehicles, such as the vehicle from CNH Case IH (Figure 11), it makes a lot of sense to not have a cab because the image communicates clearly that this is an autonomous vehicle.

Automation of existing tractors

An alternative to buying an autonomous vehicle is to retrofit an existing tractor to allow it to operate autonomously. Precision Makers (now defunct) was one company that from around 2012

Figure 11. Case IH autonomous concept vehicle, c. 2016

Figure 12. GOtrack autonomous tractor retrofit kit installation layout

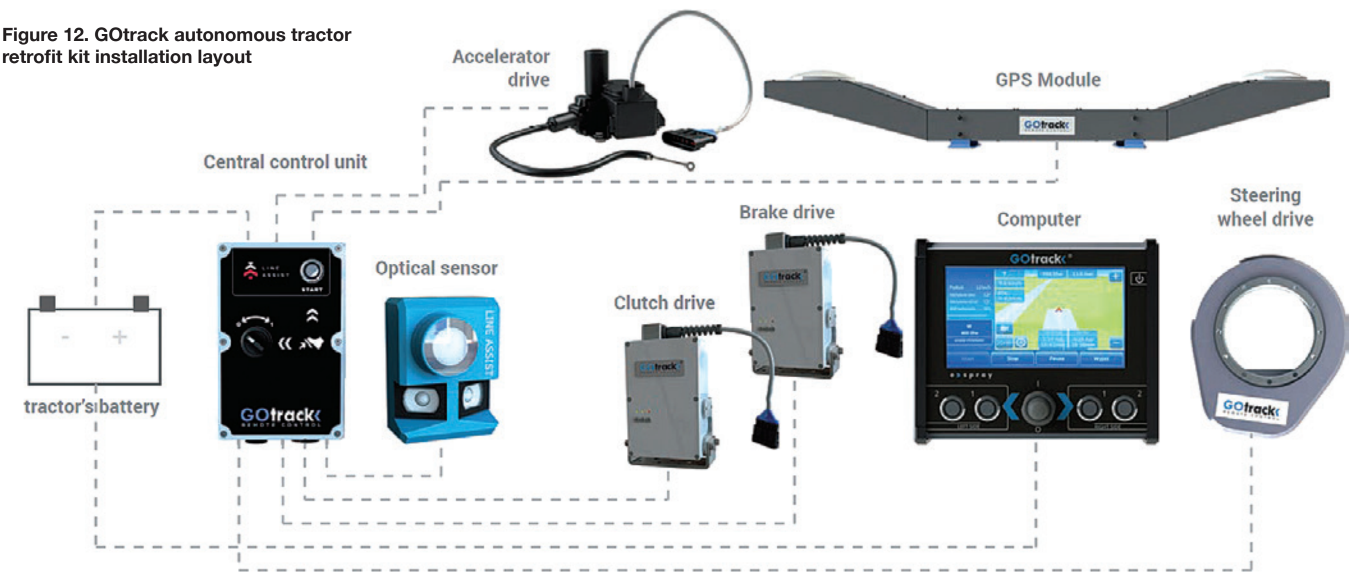

Figure 13. Tractor with GOtrack kit driving autonomously in an orchard (GOtrack 2019)

performed many conversions on agricultural equipment (Martinet 2016). Their tractor conversions cost around A$80,000 - A$120,000 (Fealy 2019, and others). The company's biggest market was in the automation of sportsground mowers, but it also automated around 40 tractors – mostly Fendt orchard tractors (Vale 2018). At least three conversions were performed in Australia. Kondinin Group (2017) reports one Australian example involving a Precision Makers system being fitted to a 326 hp Fendt tractor that was used for spot spraying and wheel track renovations. Initially the user had a few issues with the radar sensor detecting trees and obstacles on fence lines and shutting the machine down unnecessarily, but after adding a LIDAR and some other updates, performance was much improved and the customer was planning to retrofit similar systems to two more tractors. Vale (2018) reports that Precision Makers did have some issues where updates to tractor software negatively affected the automation. The Precision Makers systems appear to have been quite integrated with the tractor electronics.

A Polish company called GOtrack is now also offering an automation system for tractors (Figures 12 and 13). Their system costs around A$60,000.

Figure 14. Amos Niko crawler tractor for narrow row vineyards, where remote operation or autonomy has safety benefits when spraying chemicals since the cab is open

It appears not to integrate with the tractor's electronics too directly and the company advises that it should fit on any tractor that has power steering. Limiting the integration with the tractor electronics may avoid some of the issues Precision Makers experienced with tractor software updates. Twenty of these systems are already in use, apparently mainly in orchards. This system needs high accuracy satellite positioning. The user drives the path once and that path is then recorded in the system and the next time the path can be repeated autonomously. GOtrack offers associated systems for controlling sprayers during autonomous operation.

Other kit systems are being sold to original equipment manufacturers (OEMs) by companies such as RobotMakers which facilitate automation of their products. For example, Amos has now developed an autonomous version of its Niko crawler tractor for narrow row vineyards (Figure 14). In tractors with open cabs, there is a safety benefit to operators from using remote control or automation when chemicals are being sprayed. Amos has offered a version with cameras and remote control since 2018 and has now moved to a fully autonomous version.

Which crop sectors and businesses are likely to adopt autonomous robots and tractors first?

The easiest place to adopt autonomous robots is where large amounts of manual labour are still employed. One example is small-scale vegetable cropping. One hundred and twenty Naïo Oz weeding and towing robots (Figure 15) are now in operation. Prices for these units start from around A$17,000 up front and A$6,000 per year for maintenance and positioning services. Another example of a reasonably priced robot is the Burro in the USA (Figure 16, Burro is Spanish for donkey). This is a fruit carrying and towing robot. It is primarily used to transport hand-picked fruit from the picking row to a packing table, meaning that the productivity of the pickers can be improved. It is trained simply by standing in front of the packing table, pressing a button to get it to recognise and follow you to the start of one of the rows that you want it to service and from then on it will know to go up and down that row until it encounters somebody with fruit to load and to bring it back to the packing table. Each unit costs around A$15,000 up front and A$2,000 per year for maintenance and positioning services.

Some of the biggest savings from robotisation could potentially be in fully automating fruit picking; however, this is a complex task for a machine to perform for many fresh fruits and likely will not be widespread for some time. Furthermore, with fruits that are to be processed into liquid products such as grapes for winemaking, mechanical systems (machine harvesting) have generally already been developed and replaced most hand-picking, limiting the gains from further automation.

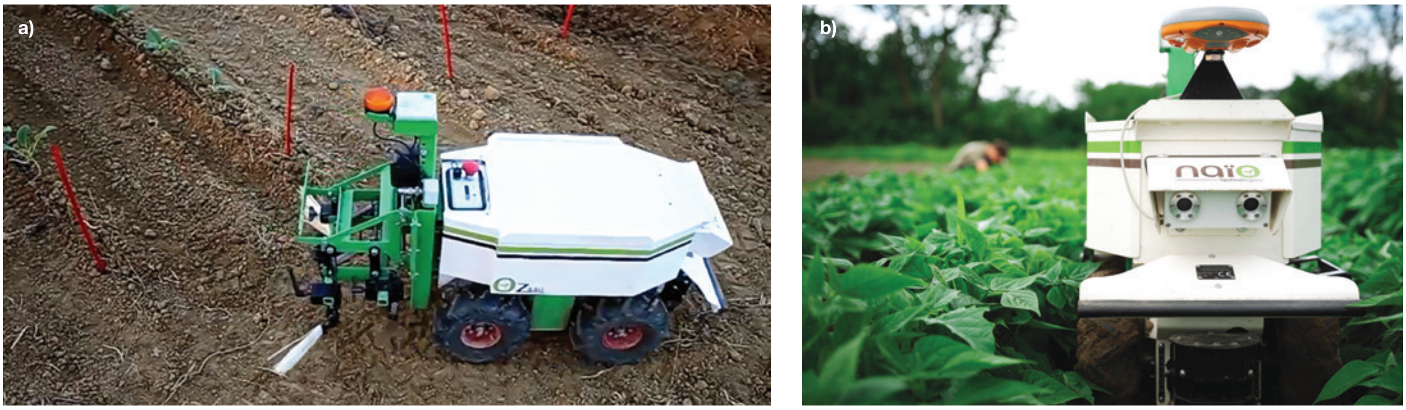

Figure 15. Naïo Oz robot: (a) Old version which relied on red rods to be installed at the end of rows when crops had not yet grown very high so that it knew where to turn for the next row, and (b) new version with guidance by high accuracy satellite positioning (allows passage even without the red stakes or crop growth that other sensors could use to detect where the row is)

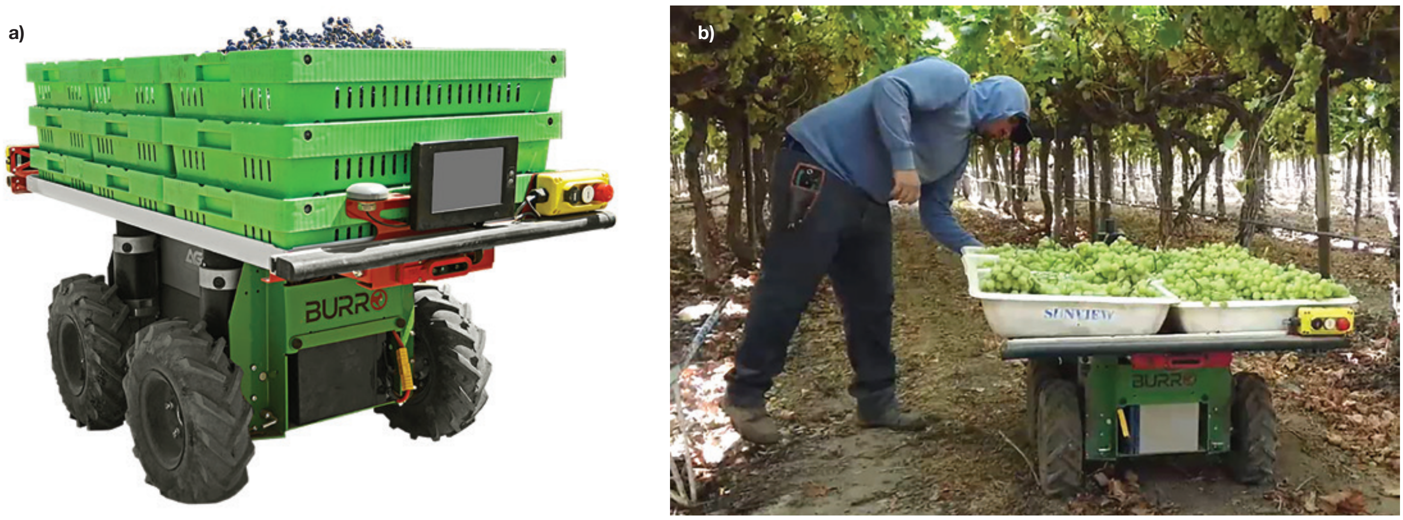

Figure 16. Burro fruit carrying and towing robot: (a) loaded up with blueberries, and (b) table grape picker pressing the screen to send the grapes from the row back to the packing table

Major tractor manufacturers (e.g. see Engel 2018, Karsten 2019) generally believe that commodity broadacre farming will not be an early adopter of fully autonomous vehicles because the scale of their equipment means that labour costs are already only a small proportion of those farms' costs and because broadacre tractors already feature a degree of autonomy through the widespread adoption of satellite positioning guided auto-steer and auto-turn (see box on levels of autonomy). Companies such as Agrointelli have already sold robots into arable farms growing moderate to high values crops like sugar beet (Green 2019). It is not impossible that other large farms might be relatively quick to adopt some of these new technologies given their experience with fairly advanced tractor and harvester technologies and the fact that they are located in remote areas where safety risks/concerns regarding autonomous vehicles might be low.

As already discussed, an increasing use of alternatives to herbicide for under-vine weed management is likely to be the main driver of adoption of autonomous vehicles in vineyards.

Overall, larger fruit and tree crop businesses with multiple tractors seem most suited to adoption of medium to large autonomous robots and tractors. One person managing a fleet of autonomous robots or tractors is likely to be much more cost-effective than having multiple people driving multiple tractors.

Safety and legal framework

The two biggest safety risks with autonomous robots and tractors are that they will leave the field or hurt someone (Seguineau 2019). In any trial or other application of autonomous vehicles it is critical that suitable frameworks are in place to prevent this ever happening, but it is also important to keep things in perspective. Agriculture makes up 2.3% of the Australian workforce, but accounts for 23% of worker fatalities and 74% of those involve vehicles (Safe Work Australia 2017). In the long-term as technology matures, it is likely that autonomous robots and tractors will end up making farming operations safer rather than more dangerous.

Autonomous on-road vehicles are a much more controversial technology. Once that technology is developed to a level where it is proven to be safer than human drivers, autonomous farm vehicles will easily be able to adopt the norms developed during those autonomous on-road vehicle debates.

Provided that autonomous vehicles stay on private property, the specific rules surrounding the use of autonomous vehicles appear to be quite limited. Wiseman *et al.* (2018) reported that "from the perspective of government regulators, for the most part, as long as autonomous machinery stays off public roads and remains on the farm and in the field, there are few regulations that regulate these new technologies". There would still of course be potential legal consequences if an incident were to occur and Wiseman *et al.* (2018) provide a discussion on this point.

Conclusions

Autonomous robots and tractors are a major opportunity for efficiency improvements in vineyards. There will likely be opportunities to trial or buy equipment over the next few years. Retrofit kits for tractors are already available and might be the cheapest and fastest initial step towards automation. How well these kits or some of the specific vineyard robots being developed in France will work in Australia will only really be known once they are trialled extensively here. The annual FIRA agricultural robotics event that is held in Toulouse, has adopted a virtual format this year because of COVID-19. Attending virtually is a good opportunity for those wishing to stay in touch with recent developments.

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Disclaimer

Readers should undertake their own specific investigations before trialling or purchasing equipment. Safety, insurance and local rules and laws regarding the use of different types of autonomous vehicles should be considered. This article should not be interpreted as an endorsement of any of the products described. Manufacturers should be consulted on correct operational procedures for their equipment.

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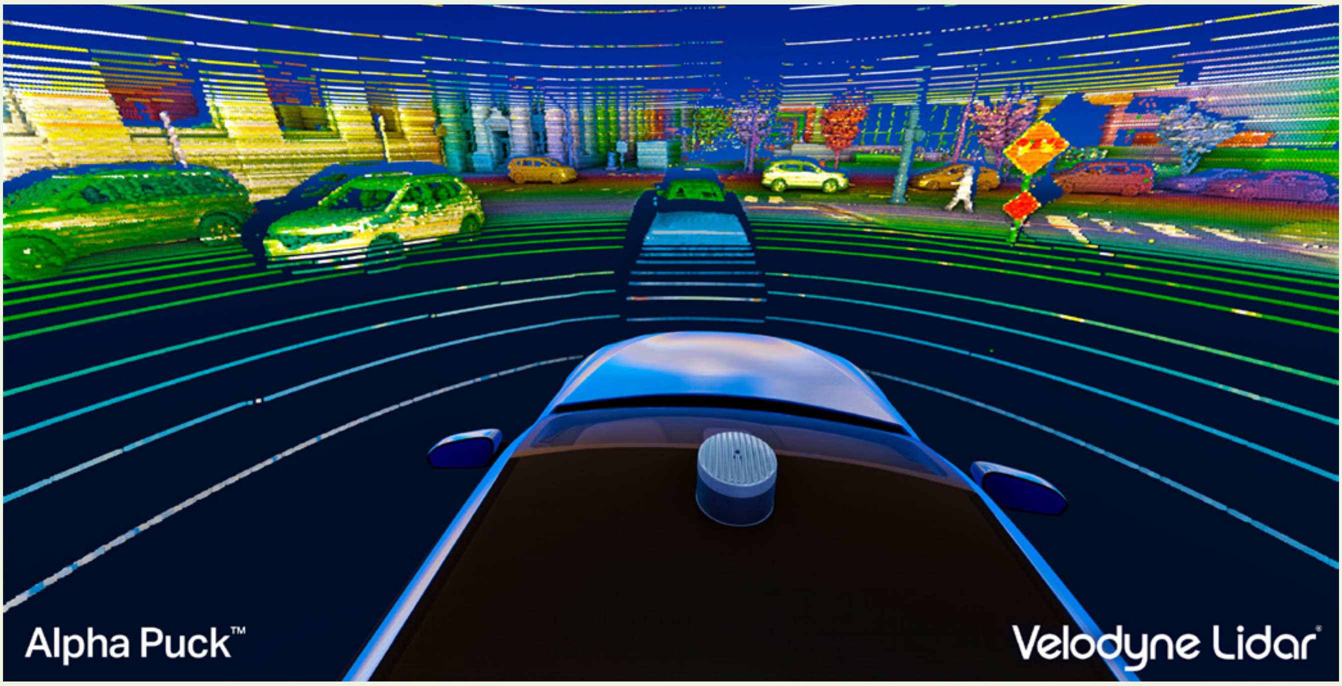
Level	Name	Description	Example features	Level	Name	Supervision
0	No automation	Only warnings / momentary assistance	Warnings for blind spot, lane departure			
1	Driver assistance	Steering OR brake/acceleration	Lane centering OR adaptive cruise control	1	Guidance	All manned vehicles
2	Partial automation	Steering AND brake/acceleration	Lane centering AND adaptive cruise control	2	Coordination and optimisation	All manned vehicles
3	Conditional automation	Self-driving under limited conditions (driver fallback needed)	Traffic jam assist	3	Operator assisted automation	Manned backup
4	High automation	Self-driving under limited conditions (no driver fallback needed)	Local driverless taxi	4	Supervised autonomy	In-field supervision of unmanned vehicles
5	Full automation	Self-driving under all conditions	Driverless taxi	5	Full autonomy	No local supervision

LEVELS OF AUTONOMY

To provide clarity on what autonomy is, the Society of Automotive Engineers developed a standard defining six levels of autonomy for on-road motor vehicles (SAE J3016 2018 – summarised in blue and green in table). This terminology has been widely adopted and is also intermittently applied to agricultural autonomy. CNH Case IH (2018 – summarised in red in table) has attempted to specifically classify agricultural automation levels within a similar framework.

There is a large jump between Levels 2 and 3 where features shift from primarily driver support to allowing self-driving under some conditions.

The widely known Tesla Autopilot system is still generally considered to only be Level 2. Under the SAE J3016 framework, some large-scale agricultural equipment reached Level 3 a decade ago (Pickel 2019), although the open-field environment they work in is less complex than roads.



AUTONOMOUS VEHICLE SENSOR TECHNOLOGIES

Types of sensor technologies used in autonomous vehicles and their pros and cons are listed below. In many cases, a fusion of multiple sensor types is used in one vehicle.

Cameras: Normal visible light cameras provide images in 2D. Two cameras from different vantage points can be used to generate a pseudo-3D image (computer stereo vision).

+	-
What humans see	Need sun or other lighting to work
Provides flat features like writing	Complex interpretation of images required

Ultrasonic: Calculates distance to objects by emitting high-frequency soundwaves (at the speed of sound: 340 m/s) and measuring the time it takes for the reflected soundwaves to return.

+	-
Works day or night	Short range detection only (< 8 m)
OK with some rain/fog	Not good with soft, curved and small objects

RADAR: (RAdio Detection And Ranging) Calculates distance to objects by emitting radio waves (electromagnetic waves travelling at the speed of light: 300,000,000 m/s) and measuring the time for the reflection to return.

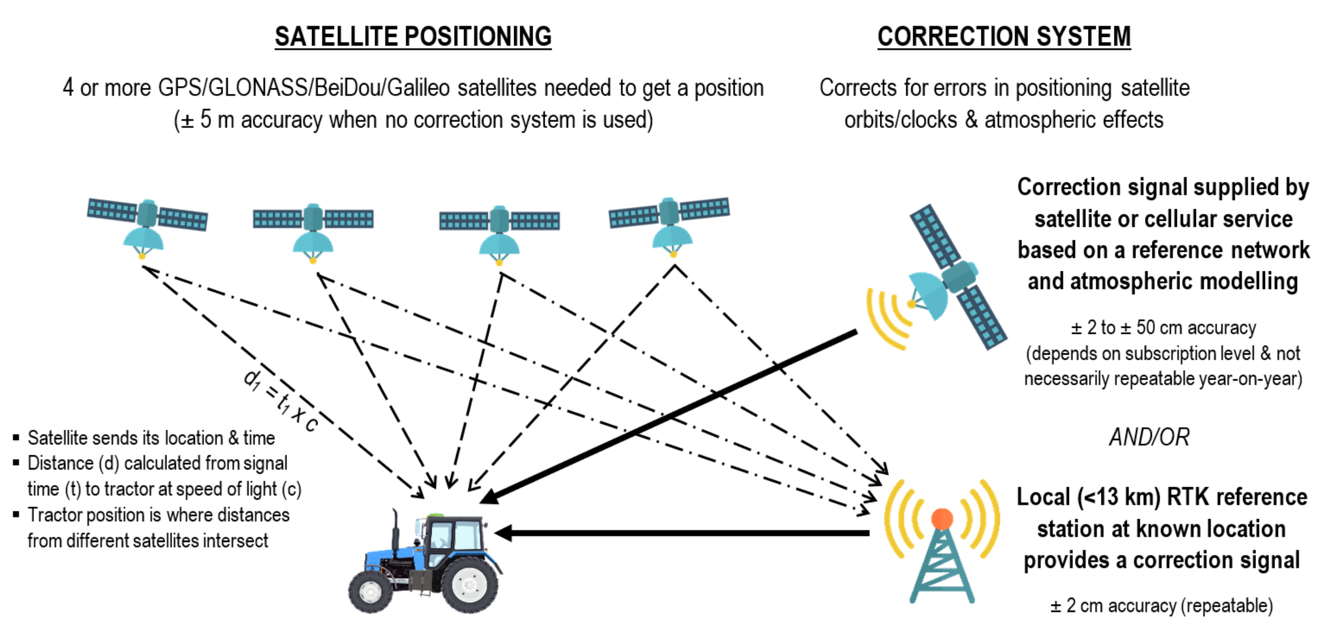
+	-
Can be used for long ranges	Cannot resolve small features
OK with rain/fog	

LIDAR: (LIght Detection And Ranging) Calculates distance to objects by emitting light and directly or indirectly measuring the time it takes for it to return (electromagnetic waves at the speed of light are used like RADAR but with a much shorter wavelength - typically infrared). The scanning LIDAR shown emits 128 laser pulses in a vertical plane, receiving 128 depth points (cheaper sensors often have far fewer points). It then rotates and repeats the same process again and again until it has a 360° point cloud from all around the vehicle (millions of data points are collected per second). The trend in LIDAR products is likely towards improved solid-state versions (Royo et al. 2019) that are small, cheap and robust but retain most of the performance of mechanical scanning LIDAR. Some solid-state LIDAR-type products already exist with varying performances – sometimes they are referred to as LIDAR and sometimes not. Famously, LIDAR is not used in Tesla cars, with Elon Musk saying in 2019: "LIDAR is a fool's errand. Anyone relying on LIDAR [in automotive applications] is doomed. Doomed! Expensive sensors that are unnecessary". Most other companies developing self-driving cars disagree.

+	-
Can resolve small features	More expensive than other sensors (but getting cheaper)
Scanning LIDAR has a long range (200 m)	Can be affected by rain and fog (Jokela et al. 2019)

(Note: Long range is critical for highway driving but less so for slow-moving farm vehicles)

Bumper: Many autonomous agricultural vehicles have some form of bump sensors positioned in front of wheels as a final layer of protection to trigger a shutdown if everything else has failed.



SATELLITE POSITIONING

The US military began developing the Navstar Global Positioning System (GPS) in the 1970s and it became fully operational in the 1990s after the launch of its 24th satellite. Other countries/groups have since launched their own systems including the Soviet Union/Russia (GLONASS), China (BeiDou) and Europe (Galileo). They are referred to generically as Global Navigation Satellite Systems (GNSS) but in popular culture they are often still called simply GPS, since that system came first. Most devices (including phones and agricultural systems) now use satellites from multiple systems not just GPS.

Accuracy from GNSS alone is generally not sufficient for agricultural applications and some form of correction signal is required. Real-time kinematic (RTK) corrections (using a user's own local reference station or a local network) are common and allow excellent accuracy. Correction signals can also be delivered from satellites or by the cellular network for an annual fee. These services are also often used to fill in gaps in RTK signals caused by obstructions such as trees and hills, as are inertial sensors. GW