Final Report

Developing Agri-Tech Solutions for the Australian Apple Industry

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AP16005

Project:

Developing Agri-Tech Solutions for the Australian Apple Industry (AP16005)

Disclaimer:

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Public summary

To develop Agri-Tech solutions for Horticulture, and specifically to the Apple Industry, by providing digital “mapping” of both flower stage and canopy development. The objective was to bring a product to market that will perform autonomous flower stage mapping and tree canopy measurement and to provide decision support for variable timing spraying specifically for primary chemical thinning. This can then be utilised by growers to make better decisions around orchard management including quality and yield improvements, reduce production costs including labour and chemical use, and increase consistency across all trees. This 3-year project had as its objective to develop a product to usher in the new digital age of digital agriculture in the Apple Industry.

This report has been provided for Hort Innovation Australia under the terms of the research agreement.

Keywords

Variable rate spraying; variable timing of application; VTA; decision support tool; apple snapper; machine learning; live processing; flower stage; flowering stage detection; canopy density.

Introduction

The objective of this project was to develop a product that will perform flower stage mapping and tree canopy measurement and to provide decision support for variable timing of application spraying. This project helped to usher a new digital age of digital agriculture in the apple industry.

This project was led by SwarmFarm Robotics with both University of NSW and ADAMA being partners in research and development of the technology.

A key output of this project is a system complete and presented ready for commercialisation. The system has been validated in-orchard and ready for industry adoption though commercial partnerships.

This project has successfully proven:

1. Live processing of flower stage / distribution images at 10km/hr
2. Instantaneous upload of data to the decision support tool website upon block scan completion
3. Growers are able to manipulate the latest data on decision support tool website to obtain an understanding of the orchards variability and growth stage
4. Growers are able to create prescription spraymaps via the web interface as the scan is finished.
5. Growers are able to load a spray map onto the Raven controller and spray a block minutes after finishing a scan
6. Accurate execution of the spraymap on a tree by tree basis
7. The tops and bottoms of trees can be sprayed at different rate
8. The final product can be retro fitted onto any existing machinery, such as tractors, side by sides or quad bikes.

Methodology

Variable Timing of Application Sprayer

SwarmFarm worked with industry to develop an orchard sprayer that utilises precision agriculture technology to apply primary thinners, specifically ATS, on a tree by tree basis. Feedback from the precision ag industry after the initial design (focusing on variable rate spraying on a tree by tree basis) concluded vastly changing the application rate was not achievable at the accuracy level desired and also resulted in off-label application. After discussion with industry, the Variable Timing of Application concept was created. This focused on targeting individual trees at the correct flowering stage with either the full rate, or nothing.

SwarmFarm worked with the industry to develop six objectives to determine the feasibility of tree by tree application:

1. The ability to switch nozzles on/off over 1 metre tree spacings
2. Accurate targeting of specific trees
3. Maintain pressure/rate while targeting each tree
4. Even coverage over the tree (spray pattern)
5. Correct droplet size
6. The ability to spray up to 8km/h

To test these objectives four phases were established and field trials were carried out.

Phase 1 - Hardware Design

When the project kicked off, the first step was to design the sprayer hardware and determine if it would be possible to actually target individual trees with off the shelf hardware. Silvan Australia were contacted and a collaborative partnership was formed with the aim to deliver a sprayer to industry that could accurately target individual trees. There were two sprayer options; a tower sprayer or an airblast sprayer. After discussions with Silvan and growers in the industry, the decision to focus on tower sprayers was made, with the belief that it would be best for spray delivery to target. Ravens Rate Control Module and Sidekick pro pumps were used as the control system on the tower sprayer. This was the best technology available that could change the application rate quickly, a requirement for tree by tree spraying. However, after testing in the orchard, it was found to take around 12 m long sections (distance up the orchard row, roughly 8 trees) to hit the target rate. Meaning tree by tree variable rate was not possible with this design.

Feedback from industry concluded that spraying an individual tree based on its flowering stage was the most effective primary thinning method. So, throughout 2020 the tower sprayer was fitted out with Raven Hawkeye control equipment under the recommendation and guidance of Matt Daniels from Raven Industries. The tower sprayer performed well in all our testing however due to the Covid 19 situation and the low hanging top wires in Batlow we were unable to test the tower sprayer in an orchard. The feedback from growers in the Batlow and Shepparton areas concluded that uptake would be low with the expensive new tower sprayer design, and that a standard airblast sprayer that could do the same job would have the best chance at being adopted by growers. So, for the 2021 flowering season a new airblast sprayer was purchased from Silvan and kitted out with the Raven Hawkeye control equipment. The following tests were conducted using this sprayer.

Phase 2 - Individual tree testing

To ensure the first 2 goals around accuracy and timing of the chemical application were achievable in an orchard, significant amounts of testing was carried out with both the tower sprayer and airblast sprayer equipped with the Raven Hawkeye control system. The main test involved mapping a series of posts location (spaced 1 metre apart) and creating spray maps based on these locations. These posts mimic trees planted 1 metre apart in an orchard. The aim was to prove the sprayer could switch on/off to target every second tree. To visualise this, butcher paper was rolled out over the posts and dye was added to the spray vat. This allowed us to see exactly where the sprayer was delivering spray, compared to where it was targeting.

Figure 1. Initial testing setup at Harden NSW

The tractor was driven 2 metres from the posts with the prescription map loaded to target every second spacing. Multiple passes were conducted on fresh paper with different configurations in the Raven Controller until the spray application was hitting the desired target positions. Figure 2 shows the final results from this test. You can see that every second spacing in the image is coloured pink from the die in the tank. This test was conducted at 8km/hr, giving confidence the sprayer system could operate in an orchard, targeting every second tree at the desired speed. It also demonstrated that we could fully turn on and off every nozzle every metre spacing which we determined would be as narrow as possible while still giving adequate coverage to the 'on' sections without over-spraying the 'off' sections. From the prescription maps generated during this season, it was noted that very rarely does the sprayer encounter a row where every second tree is much more or less advanced. Usually, the trees are more consistent with a few outliers. This means the sprayer will not have to perform the amount of switching we demonstrated during testing.

Figure 2. Results from fence line testing in Harden NSW

Phase 3 - Flow rate validation

The next tests carried out ensured that the flow rate from each nozzle was correct. This was completed in November 2020. A hose was placed over a nozzle at random which then directed the flow out of the nozzle to a bottle. The volume in the bottle was then compared to the applied volume that should have been sprayed according to the prescription map. The flow rate tests were successful, proving application rate was correct even when switching nozzles on / off at close intervals.

Figure 3. An Example of nozzle flow rate testing. source: https://sprayers101.com/

Phase 4 - Orchard testing

Phase 2 and phase 3 testing gave confidence that variable timing of application spraying was achievable within an orchard. The configuration of the sprayer was tried and tested, the next stage was to determine the accuracy and coverage when operating within the orchard row. Several trials were completed in consultation with Sally Bound, Senior Research Fellow at Tasmanian Institute of Agriculture, agronomists, and Growers in the Batlow area. These trials were focused on droplet size, coverage and penetration into the foliage at different speeds. Dye was used to test the overall coverage as well as droplet size and overspray along an orchard row. After promising results with the dye, water sensitive paper was then used to conduct more accurate and measurable tests.

Figure 4. The sprayer spraying the top left and bottom right sections of trees

Much like the fence line tests, each individual tree's GPS location was mapped. Shapefiles were output of these locations and a prescription map was generated to spray each individual tree and not spray the rest of the block. Water sensitive paper was then placed at different distances from the mapped location to determine the accuracy of the Raven system, when targeting an individual tree. It was then only a matter of trialling different speeds to ensure consistent results were found in the orchard that matched the accuracy to the paper fence line test.

Once the accuracy of the system was validated, focus turned to the coverage of the sprayer. Water sensitive paper was placed in the rows behind the tree being targeted. These tests are outlined in detail in Appendix 1.

Apple Snapper System

The apple snapper system describes the complete data collection pipeline from capturing images, processing with flower stage/intensity and canopy density algorithms, automatic upload, to viewing on the decision support tool webpage and outputting an application spray map. The steps of the process as follows.

- Data collection / scanning of trees.
- Live image processing.
- Automatic upload and storage.
- Decision Support Tool Website to help the Grower visualise the orchard.
- Generating the prescription spray map from the data.

Figure 5: Full system pipeline developed from data collection to spraying with application maps

The final data collection system based on feedback from growers and the latest research in agricultural machine vision and automation was developed and fine-tuned over 3 seasons in orchards. The final system consists of multiple hardware and software modules working together to make a seamless process from data collection to spray map output. Outlined below is the methodology and justification of the research and verification done to produce the final product.

Hardware Selection

Hardware selection was considered first, with different cameras, LiDARs (light and detection ranging), GPS, IMU (inertial measurement unit), computers tested and evaluated to get the best results possible.

- Cameras were chosen on the basis of how much detail was needed to correctly identify all stages of the flowering life-cycle, from pink tip through the petal fall. It was important for early stage estimation to have a high enough resolution to be able to see the tip/ bud development.
- Different wide angle lenses were sourced and tested to ensure the whole tree, in different common row widths, could be captured with minimal distortion. Final costs were reduced as testing showed that only one camera per side was needed to capture the full tree, thus eliminating the need for multiple cameras and complex software for syncing the images together.
- The collection rig's location in the orchard was a critical component so significant time was taken testing multiple systems to achieve the best accuracy. These tests involved driving through the orchard and plotting the positions of what from different GPS receiver systems. The final GPS has an integrated IMU with its own filters so there are no drop-outs or jumps in the data when driving under trees.
- During the early development of the image detection models, the images were captured and then sent to UNSW for processing. Once the Image detection models were built and validated, focus moved to enabling local processing of images to eliminate the need to upload and send images from the field to UNSW for the processed output. Edge AI computers have become very powerful and energy efficient due to the research for autonomous cars and robotics, which need highly efficient powerful computers to process the many connected safety devices. This technology enabled us to shift to the ability to test live processing of images, without the need for large power sources. The final platform used was the Jetson Xavier SOM with a Neousys Carrier board that expanded the number of ports for the cameras, GPS, LiDAR and 4G/Wifi Modem.
- Initially a large lattice structure was used to test numerous cameras and lighting arrays. However, once the camera and lens selection were finalised the structural design was focused around their ideal position. Next, many flood lights were used to capture consistent images which had to be adjustable for different settings, however in the final season strobe lights allowed the structure to be much more compact.

Software Development

The software underwent many different iterations throughout the project. Early on it enabled quick turnaround testing of new components and collection methods but was not optimised for a commercial product. Once the final hardware was selected, work was done to test live processing and capture. The specific AI Computer we chose allowed us to optimise the image detection models to run much faster on the selected hardware enabling live processing for each tree at 8km/h. The system can also be configured to process every second tree in the orchard, to give a lower resolution map of the orchard. Speeds of up to 30km/hr can be achieved when only processing every second tree.

The final software stack underwent a large refactor in the final year of the project to increase the robustness and error handling ability required to allow for operation by growers. The code was also stripped back and modularized to make maintenance straightforward.

The user interface was not developed until the final season due to regular changes in internal software communication formats during development. Once the hardware, inputs, and outputs were finalised, a user-friendly user interface with the ability to control and debug all aspects of the collection rig was developed.

Connected system

To make the process from capture to producing a spray map as seamless as possible, a full pipeline was implemented to push data from the Apple Snapper to a cloud service. This means growers do not need to manually handle or sync data. To get the user started as quickly as possible, boundaries for blocks can be created on a map that is loaded automatically to the collection rig. The user then inputs the required settings such as row and image spacing and it is then a one button press to start recording. The user can continue to drive as many blocks they want until finished and then can confirm the data collected and upload straight to the cloud. Once uploaded the maps are available immediately in the decision support tool website.

The Decision support tool development was not completed until the final hardware, software, and file formats were decided on. This allowed us the freedom of not being locked into a single format early on and the ability to select the best format based on a complete set of information. The key part to validating the usability and value in the decision support tool was being able to represent and manipulate the data in an intuitive way to the growers, allowing them to make the most informed spray decisions. Work went into informing and showing growers the data collected in many different formats. Feedback from these discussions contained important insights into the information the grower wants to see to make the best informed decisions for their orchard. An overview of the features available on the Website are expanded upon in Appendix 5.

Training Pipeline

A quick turnaround training pipeline was developed to quickly re-train the algorithm models as new data sets were captured during the season. 40 quads (0.5m X 0.5m) were placed in trees and were counted/classified three times a week throughout the season. The location of each quad was known to the Collection Rig so images with quads were able to be captured separately and sent through to UNSW when scanning was complete. All flowering buds were then counted and classified by an agronomist and were passed onto UNSW who were then able to quickly process the new images and counts to improve the imaging algorithm models. This streamlined process allowed us to rapidly get more accurate maps as the season progressed.

Some of the quads were also used as validation and accuracy indicators to see how much improvement we were getting with more trained images. As the quads were consistently at the same height across the block, they did not represent the full variability of an apple tree. Therefore, larger full sized quads were imaged and counted to be used as additional validation when analysing the trained models.

Throughout the flowering period we walked through orchards in the Batlow area with growers and agronomists. During these walks we discussed thinning decisions on a tree-by-tree basis. The location of these trees was then brought up on the decision support tool, with the image of the location being matched to the tree we were looking at. This was used to improve grower trust in the system as they could use their experience and judgement to guess what stage the tree is at themselves, and whether they would want to spray it. We could compare the growers summary of the tree to the data we had recorded, and after going through this process for a few trees their confidence in the system improved drastically.

Results

Variable Rate Sprayer

Variable timing of application and variable rate spraying were achieved in this project. Growers can utilise the spray technology developed in this project to spray specific trees within an orchard at a particular growth stage (i.e. 70% king bloom and above) with a particular rate (1000L/ha). This has been proven to be accurate and effective. An industry know-how guide has been developed to give growers and spray manufacturers the technical details on how to configure any Airblast or Tower sprayer to have variable timing and variable rate capabilities.

The sprayer was able to:

- Action the user-defined prescription map to deliver variable rate and variable timing of spray application
- Accurately target spray applications independently between top and bottom sections of the canopy
- Track coverage area and record as-applied maps for regulatory documentation

Current product features:

- Variable Rate Application - spray the top and bottom half of the tree with different water rates, as defined by the DST user.
- Section Control – actioning pre-defined prescription map to only spray those trees that are at the correct flowering stage (VTA – Variable Timing of Application)
- Output at the completion of a spray application, an 'as-applied' spray application map

Both the airblast and tower sprayer performed extremely well throughout the years of testing. Feedback from industry concluded that updating current airblast sprayers is the most likely avenue for broad adoption. The tower sprayer may be more accurate, however it is not suitable in orchards with low wires and it has a far greater cost. It is recommended that farmers maintain their current airblast sprayer, and attach the kit to it, thus reducing capital costs of the technology adoption. This would be a huge improvement to production and productivity within the industry.

Apple Snapper System

For the final product of the project, focus was directed on producing a commercially rounded product that demonstrated the full features developed in this project. Some of the key areas that were prioritised included:

- Optimisation and streamlining the software stack
- Creating a more user-friendly interface for controlling and monitoring the Collection Rig
- Automatic upload and storage of images and produced maps
- Redesign the Collection rig to a more compact unit
- Integrate strobe lights to enable faster collection

All these solutions were developed in time for the 2021 flowering season and only minor adjustments were needed during the season. Data was collected in the Batlow region over 6 weeks across 10 blocks. The two collection rigs recorded over 150 hours each with over 1.5 million images captured and processed in real-time. All the processed maps and a subset of images were uploaded to the cloud and viewable immediately on the Decision Support Tool Website. The details of the improvements and high-level details of the final product is located in Appendix 4

Image Detection Models

The resulting data collection system centres around the image detection models developed by UNSW which output the intensity and stage data extracted from the images. UNSW's report will go into more detail into the methodology and results acquired in the development process. The final models allow for the detection of the 8 stages of an apple flower from green tip all the way through to petal fall. Detecting each stage gives valuable information on each individual tree and its stage in the flowering process to the grower, allowing for more targeted decisions around the timing of application.

Outputs

Table 1. Output summary

Output	Description	Detail
Magazine articles and written communication	There were six articles published throughout the project, providing updates to industry.	The articles were published in industry magazines, including APAL magazines, Fruit Grower Victoria publications. The URL's are provided below • https://apal.org.au/agritech-to-help-with-thinning/ • https://www.futurefarming.com/tech-in-focus/swarmfarm-and-green-atlas-develop-thinning-robot-for-apple-orchards/ • https://apal.org.au/swarmfarm-new-apple-agritech-project/ • https://apal.org.au/automation-variable-rate-spray-swarmfarm/ • https://afdj.com.au/apple-growers-get-robot-technology-to-increase-yields/ • https://www.agricultural-robotics.com/news/australian-market-of-agricultural-robotics-robots-under-project-part-2
Orchard walks	The future orchard walk program was used to promote the work done in the project and update growers in the industry.	The first two years project staff attended and presented at all future orchard walks. However, with the COVID restrictions of the last two years this has not been possible.
Annual conference (Hort Innovation)	Attend the Hort Innovation conference and provide an update to the industry.	All Hort Innovation conferences held throughout the project were attended. We were unable to obtain a speaking position at the conferences. SwarmFarm were able to utilise the ADAMA conference stand to show the robot and generate discussion and excitement amongst growers. Many growers took the opportunity to talk to project staff individually.
Annual video summary	Create a video to summarise the yearly development and promote the project to industry.	Throughout this project 8 video updates have been recorded. 3 have been yearly updates to show progress of the project. The last 4 videos are explainers to assist in adoption and update of the final product. A playlist of videos has been created, these can be found at the following link. https://www.youtube.com/playlist?list=PL5bCp1wH-n10zZH4YPYZ6ZS959jiYB1Tm
Industry guide for sprayer	The industry guide outlines in detail how to build a variable rate sprayer.	SwarmFarm has utilised "off the shelf" components from the broadacre industry to develop a variable timing of application spray system / solution that can be fitted to any tower or airblast sprayer. The commercialisation path for the sprayer is via an "industry know how" guide (appendix 6). The intention of this guide is to explain in details:

		● Hardware component list ● Hardware installation guide ● Sprayer configuration ● Importing and utilising prescription maps This guide will be distributed via industry channels to growers and spray manufacturers for widespread adoption. The hardware used in this project has been sourced from Raven Industries and is readily available and supported. Similarly, there are competitors to the Raven control system that are able to modify the setup of their existing spray hardware and computers, to deliver the same functionality. This is ideal for the industry and should lead to multiple manufacturers offering competitive systems to Australian growers.
GIS protocol for orchard mapping for autonomous operation	A GIS convention was developed throughout this project for georeferencing an orchard. This is used by both the flower stage estimation platform as well as the SwarmBot system	End row posts were surveyed with RTK GPS as well as an overall boundary polygon for each block. The row end locations were used to generate obstacle 'zones' around every row of trees in the orchard. The SwarmBot used these obstacle boundaries to make sure it never generated a path that hit or damaged a tree.
Localisation solution for orchard operation	Ability for farm vehicles to accurately localise (understand its position in the global environment) within an Apple Orchard so precision agriculture practises can be utilised	Precision agriculture utilises highly precise GPS positioning for its field practises. In broadacre this includes, variable rate maps, auto steer and many more field applications. GPS and precision agriculture is currently not commonly used in the Apple Industry. GPS is an absolute global reference to a position on the ground. SwarmFarm recognised the benefits of using GPS technology for both the data collection rig as well as the sprayer. The benefit of this is all data is referenced off the same positions. There is no need to estimate / localise off tree trunks etc. The reason GPS is not commonly used in orchard environments is due to the canopy shadowing the receiver, causing intermittent dropouts. SwarmFarm worked with a third party company to test and improve firmware for IMU + GNSS fused GPS hardware, with the final solution being a robust GPS system for orchard applications.
Communication solution for orchard operation	The method of communication within an orchard is dependent on many factors. Including orchard location, proximity to 4G towers, orchard density / spacing, tree height and antenna configuration on-board the SwarmBot.	SwarmFarm has partnered with various communication providers to trial different solutions for machine communication in challenging environments. Trials that have been carried out include: 1. 4G link to service provider – i.e., Telstra/ Optus 2. Local LTE tower on farm - essentially a local 4G tower with a backhaul link to the internet 3. Multi-carrier systems - Multiple models that switch

		between the various carriers in real time to maintain optimum bandwidth 4. Satellite link via Iridium network 5. Local Wi-Fi meshing network consisting of various local nodes, connected via a backhaul link to the internet Due to the close proximity of a Telstra tower in the Batlow region, SwarmBot Papa was able to continuously communicate over 4G while operating autonomously, allowing for consistent communication to connected devices. The Wi-Fi was also demonstrated to be an effective communication mode when operating nearby. As both of these options were sufficient in providing maximum safety and operation control, no other communication solution was required. However, for orchards that do not have a stable 4G link, there are multiple communication solutions that can be tailored to fit. SwarmFarm recommends a private LTE networks as the best solution for farms outside of good cellular coverage areas.
Safe obstacle detection system for autonomous operation in an orchard	SwarmFarm has developed early stage algorithms for safe obstacle detection in orchard environments. The development and work undertaken in this area was completed outside of this project, however we were able to utilise the technology to demonstrate safe obstacle detection within an orchard.	There are two standalone obstacle detection systems that SwarmFarm utilised for obstacle detection within an orchard. 1. **LiDAR / Time-of-flight** sensors are used to detect large obstacles as well as determining the traversability of the upcoming terrain. This system was originally developed for broadacre applications, but was able to be modified to operate in orchards by filtering tree limbs that overhang the row. This method is still under development and currently has a high count of false positive detections. However, we are certain this can be improved with further development. 2. **Human Detection** system utilising machine learning is another obstacle detection system used in orchard environments. By using machine learning methodologies, we were able to accurately detect humans and if a person stands near a SwarmBot it will recognise their presence and stop until they are safely out of the way.
Tree measurements system	System to scan the orchard canopy and output tree measurement estimations. These measurements can then be used to estimate tree row volume for efficient spraying.	The final system can reliably output tree height, tree width, and tree density. Is comprised of: 1. 2D (SICK LMS100) or a 3D (Velodyne VLP-16) 2. Jetson Xavier (computer) 3. Novatel SMART7 GPS receiver The point-clouds outputted by the LiDAR is processed in real-time by the on board computer utilising filters for identified

		tree netting as well as using the row-ends to accurately create a 3D map of the orchard. This data is then output in standard Raster files that can be viewed and manipulated in any GIS software. The data can be used to calculate Tree Row Volume for that particular scan, giving the grower accurate insights into their orchard at different times throughout the flowering season. It has been demonstrated that LiDAR can be used to produce accurate canopy maps including tree height, tree width, canopy density, and detecting missing sections. It has also been shown that this can be achieved in real time in different orchard environments. The feasibility of eliminating the need for expensive hardware has also been explored with the use of camera algorithms instead of needing the LiDAR data. Doing so brings down the overall cost of the Collection Rig making it more attractive in price to more people.
Flower stage estimation system	Data collection system that could process images taken of an apple orchard and process in real-time to produce data map viewable on a website.	The final system developed for estimating the flower stage of apples trees has the following features: ● Capture full height images of every tree in an orchard. ● Process images in real-time travelling at 8 km/h. ● Get live-stream images and processed data to the Control Interface. ● Process multiple blocks in any order and any row-width. ● Instantly upload outputted data to the Cloud, ready to view on the Decision support tool. The tangible outputs consists of: ● Compact Collection rig that can fit on a Polaris with the following parts: ○ Laser-cut frame ○ Custom wiring harness ○ Off-the-shelf waterproof case ○ 2x Flir Blackfly S cameras with Fujinon 8mm (focal length) lens and CEI rugged enclosures ○ 4x Phoxene strobe lights ○ Novatel Smart7 + Relay7-400 radio ○ Teltonika 4G/Wifi router with John Deere antenna ○ Jetson Xavie Carrier board ● Full Computer image that can be flashed onto AI

		computer • GitHub repository with core collection code • Advanced AI image detection models trained on 3 years of data in Shepparton and Batlow An IP agreement has been developed to licence this technology to a commercialisation partner. See below for further details.
Testing pipeline for training datasets	Quick turnaround process for collecting images with ground-truthed data and training a new model	In conjunction with the development of the Collection Rig a quick turnaround training pipeline was developed to rapidly re-train the algorithm models as new data sets were captured and ground-truthed during the season
Online solution for viewing and creating spray maps	Online database and website for storing and viewing produced flower stage/intensity maps from the collection Rig as well as outputting spray maps. This Decision support tool is for being able to visualise the stage and intensity maps to the grower to help them visualise the variability in timing and flower load of their orchard.	All the data collected during the 2021 season at the orchards in Batlow is available to view online through the decision support tool website. The source code for the website, data formats and database configuration will be provided in a GitHub repository in conjunction with the commercial partner taking on the flower stage software/hardware. The website was created to make the data more accessible and easier to visualise to help growers make more informed decisions utilising their spray program with the data collected from the Collection Rig.
IP agreement for technology transfer	SwarmFarm and Hort Innovation have developed an IP licence to transfer the Apple Snapper technology developed in this project to a partner that will deliver it to industry. The licence has been developed to reduce the roadblocks that normally exist around IP transfer	Commercialisation is currently being explored. At the time of writing this report, several conversations were underway with third parties, to ensure the transfer of the Apple Snapper technology and will be widely available to industry For commercial opportunities please reach out to Hort Innovation.
Variable timing of application	This is a concept that was developed throughout the project to target all areas of the orchard at the desired time rather than a one size fits all approach. A grower selects the growth stage they want to target for primary thinning, e.g.60% king bloom. Any tree that is 60% KB or above would be targeted on this application while areas that have not reached the desired 60% KB would be targeted in	Initially the project called for variable rate and variable concentration application to individual orchard trees. However, after talking to growers and working in the industry for two years, it was apparent that the biggest factor in fruit load management was the timing of the application. Not necessarily how much of a chemical was used, or the water volume. Also, variable concentrations rates would mean off-label use of chemicals which goes against APVMA regulations. SwarmFarm developed this concept after releasing the impact timing had on fruit load management. This concept was already in use by some farmers, who would manually switch the sprayer on / off as they drove through the orchard, relying on their experienced eye to make the call. The technology that has been delivered gives all growers including the more inexperienced operators the ability to variably time their thinning application. Over time this will reduce the variation of

	another application.	fruit throughout the orchard block.

Outcomes

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
A product developed and ready for commercialisation	Outcome (1) in project proposal	The final product has the capabilities to: ● Collect and process camera data at any stage of flowering ● Collect and process LiDAR scans to determine, height, width and density of canopy ● Using machine learning algorithms, determine the variation in crop load and the stage of growth (percentage of flowering) of each tree in the block ● Output common GIS data formats ● Present a simple intuitive user interface to the grower/agronomist via a webpage ● Visualise tree height, width and canopy density, and allow growers/agronomists to calculate tree row volume, or similar spray calculations using these data layers ● Visualise the flower load and flowering stage (percentage flowering) throughout an orchard block. ● Allow the user to develop a site-specific management plan (prescription spray maps) by selectively combining tree metrics,	Project staff interacted with growers and agronomists from the industry regularly throughout the project. Feedback from growers made it evident that the original project calling for flower counting and variable concentration spraying was not actually what the industry needed. SwarmFarm took this on board and undertook a variation to the project scope to ensure the final product delivered was a solution the apple industry needed.

		data on crop load and flowering stage • Export a standard format prescription map that can be accepted by a variable rate spray system	
The product will provide functionality as specified above	Outcome (2) in project proposal	There are multiple technologies working together to deliver the final product target of tree by tree flower thinning. SwarmFarm's role was to produce a system so anyone could use the algorithms developed by University of NSW to improve productivity on their orchard.	The functionality has been simplified in response to industry demand. Minutes after finishing a scan the prescription map can be loaded into the sprayer and the spray operation commenced. Timing is crucial in any agricultural enterprise and the feedback received was heavily focused on the technology being functional. Product features: • Ruggedised and weatherproof modular unit • Mounts to either a standard frame tractor, utility farm vehicle (i.e. Polaris) or SwarmFarm robotic platform • On-board GNSS positioning system • Onboard data storage, image and LiDAR processing • Mobile data connection for data export • Provide functionality within the system that will allow the grower/agronomist to create customisable management zones, within an orchard. Each management zone may consist of single or multiple trees, and can be selected based on logistical or hardware (sprayer) limitations • Allow the user to identify heavier and lighter crop loads throughout an orchard block and develop a high-level management plan for the season to determine the spray strategy, i.e. more and/or earlier spray

			applications in heavier management zones • Allow the user to then selectively filter for management zones that are at a particular stage of flowering (i.e. show all trees greater than 50% flowering) and generate a prescription map from these zones • Identify scouting locations (regions of high or low density) that may need further investigation
The product is supported by 3 years of trial data	Outcome (3) in project proposal	Over the last three flowering seasons there has been 3 times weekly scanning with the data collection rigs. This data was then reviewed and used to start discussion with growers/agronomists. Each scan had a series of quads that were counted by professionals in the area. These were cross referenced to ensure the accuracy of our collection along with the flower detection algorithm. Sprayer testing has been carried out over the last three years in and out of orchards to ensure the ability of the variable timing of application sprayer to accurately target individual trees.	The technology has been rigorously tested in different locations, orchards and tree varieties. The sheer volume of data collected and processed is proof to the industry of the quality of the data collection system and variable timing of application sprayer.
A high-level of awareness of the product within the apple industry measured by adoption rate/volume	Outcome (4) in project proposal	Industry awareness has been increased through industry engagement at every step possible, however ROI and adoption will need to be reported on by Hort Innovation at a later stage.	Videos and conversations have been the best way to gauge the interest and potential adoption by industry. In depth conversations with growers created the list of information that needed to be covered in the videos. Correctly conveying the ruggedness, simplicity and benefits of the full stack of technology from the data collection rig to the sprayer substantially increased the awareness in industry. Short videos packed with technical information mean growers can see and understand how the system works and the benefits it will have to their operation.
Sprayer setup and configuration		Creating a build-guide for distribution among sprayer manufacturers and growers	Conversations with many growers highlighted a lack of understanding of what the currently available spray

		within the industry. The guide will cover installation, configuration, setup and operation of the key components of the sprayer system. The aim of the industry guide is to facilitate a larger uptake in knowledge on how to utilise the large quantities of variability data available to growers. Giving this information freely to growers will increase the demand for data collection of different types within horticulture as a whole.	technology is capable of doing with regard to variable rate application from standard shapefile spray maps. Proving that tree by tree application is possible will raise awareness that this technology is here now and will create a demand for more data collection around orchards, not just flower stage and intensity.
Sprayer hardware off the shelf and available		The use of off-the-shelf hardware gave confidence to growers that the technology and support was tried and tested and could be relied upon.	Sourcing information from different industries such as broad acre in Australia and overseas, the latest technology was found and tested to see if it could apply to Horticulture.
Improved grower understanding of variability within their orchard		Data collected from orchard blocks was regularly displayed to Growers in different formats to generate feedback on how best to display data in a user-friendly and effective way. Highly interactive data maps on the Decision support tool allow growers to see intensity and stage variability in their orchard with the click of a button.	Feedback from growers and agronomists was by-annual bearing was the biggest issue. Therefore, statistics as a whole block or row was not of value. Being able to see and target overperforming trees and notice underperforming trees in time will allow growers to have a much more consistent product to market year in year out.
Grower confidence in technology		Field walks were conducted with growers to show the data outputted by the Intensity and Stage Algorithms. Growers could see from tree to tree how accurate the produced maps were in comparison to the grower ‘feel’ of their own orchards.	Having growers in the loop providing feedback ensures the product will be suited to its market. Having growers looking at the tree in person while looking at its photo in the decision support tool built confidence in the technology. Working with agronomists meant growers in the area were represented through their technical representative, not just those who had hands- on experience with the technology.

Recommendations

SwarmFarm has compiled a list of recommendations for future work that could be undertaken in this area to further benefit Apple and Pear growers.

- Remove the dependency of LiDAR on the canopy mapping system. SwarmFarm believes the Flower Stage Detection algorithms could be updated to include canopy mapping estimation. This would reduce the overall cost of the unit.
- Hort Innovation has funded an excellent R&D project and SwarmFarm has built and delivered the technology ready for commercialisation. We believe the next step of this project should be a fully funded ROI with a commercial partner of the complete system. A three year project that utilises this technology and looks at thinning results, fruit yield, fruit quality and orchard variation would give growers confidence in the technology. We believe this is needed for large scale updates. Other companies collecting data using LiDARs, cameras, drones and satellites should be engaged to produce maps executable by spray systems such as the one used in this project.
- Continued research and development into precision agriculture technology suitable for orchard thinning. Conversations with Raven engineers in the USA spoke of new technology that could be more suitable for orchards. Newer spray control systems should also be looked into due to the fast moving nature of agriculture technology development, the sprayer control system used in this project was just an example of what can be done.
- Crowd sourced image collection with ground truth data is another way to expand the robustness of the algorithm in different growing regions. This would increase accuracy in different climates and factor in multi-year growing cycles
- Creating an iPhone app that can be used for:
    - Collecting training data
        - I.e. farmer could take a photo of a tree and input the stage distribution from manual counts
    - Quick scan of trees
        - Growers could take a photo of a few trees in the orchard and get feedback on flowering stage

Intellectual property

Intellectual Property available for licencing

This project has generated the following intellectual property available for licencing through Hort Innovation.

1. Apple snapper software
    - Collects and stored datasets on the fly for algorithm training
    - Interfaces with external hardware to capture images at the correct location and spacing
    - AI Algorithms for detecting flower stage and canopy density
    - Real time AI analysis
2. Decision support tool
    - Cloud infrastructure for secure storage of datasets and online syncing of processed data
    - Decision support webtool for farmers to interact with flower stage data for better decision making
    - Prescription map creation for spraying / targeting individual trees.

Other Intellectual Property generated in the project

The project has also generated some know how that has been documented into an easy to access guide. This industry guide (appendix 6) documents the learning made throughout the project and gives detailed information on how to configure an orchard sprayer to target individual trees.

Appendices

Appendix 1 - Sprayer

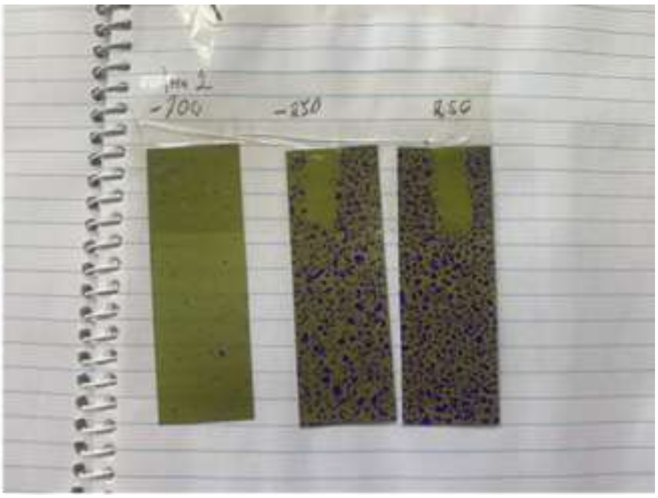
Measurements and Results of testing in orchard

A series of tests were carried out to measure the accuracy of the nozzle activation and shutoff of the Raven system within an Orchard. The tests were carried out at 4 & 6 km/h, targeting a tree defined as 1m wide. The distance between trees was around 1.5 meters. Water sensitive paper turns to a dark purple colour anywhere a droplet hits the piece of paper, it is usually used to determine the droplet size of the chemical being applied however we have used it to determine exactly where the droplets were landing and therefore the measurable accuracy of the sprayer.

Test 1

Water sensitive paper was placed (in order) -900, -450, 0, 250, 700 mm from the centre of the first tree, then a tree was not sprayed, then water sensitivity paper was placed -700, -250 and 250 mm from the centre of the second tree. The results are shown below.

(a) Run 1 first tree



(b) Run 1 second tree

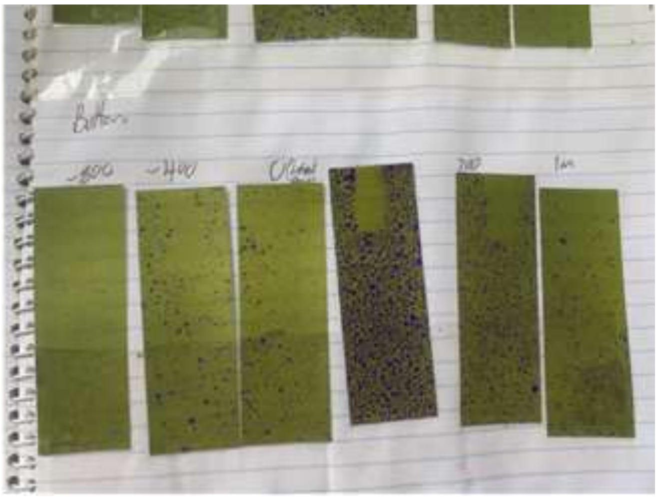
Figure 6: The first recorded test run

In a perfect world we would see no droplets on the water sensitive paper greater than 500mm from the centre of the tree. We found that wind had a significant effect on the location where the droplets landed. We also found that any water sensitive paper that was behind some foliage or a branch had many less droplets which made it difficult to determine the accuracy of the nozzle activation/ deactivation.

Test 2

Water sensitive paper was placed -800, -400, 0, 400, 700 and 1000 mm from the centre of the tree at 2.5m off the ground and 1m off the ground.

(a) Run 2



(b) Run 2 bottom results

(c) Run 2 top results

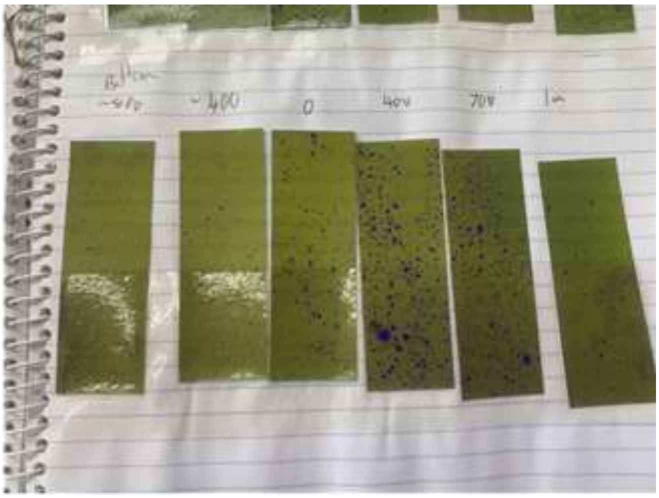
Figure 7: The second test run

These results confirm the accuracy of the system, with most of the droplets within 500mm from the centre of the tree. The nozzles could be seen to be switching at the correct location, however again the wind and the fan of the nozzles saw some of the paper outside the tree area have droplets land on them. There seemed to be a trend with the paper after the target having droplets on them, to try to combat this issue we increased the distance between the GPS and nozzles in the Raven software.

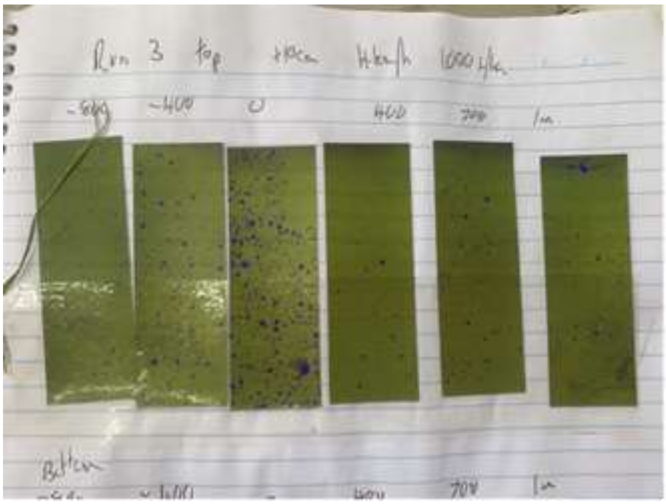
Test 3

In the third test run, the distance between the GPS to the nozzles in the Raven software was increased by 100mm. This was to try to combat a trend which we were noticing that was believed to be late nozzle activation/deactivation. This in hindsight made the results worse, however the results are below.

(a) Run 3



(b) Run 3 bottom results



(c) Run 3 top results

Figure 8: The third test run

Test 4

The fourth test was carried out at 6km/h, the distance from the GPS to the nozzles was also shortened by 100mm (from the original measured setting) to make the nozzles turn on earlier with respect to the mapped location. The water sensitive paper was placed -700, 0 and 700 mm from the centre of the tree, with extra water sensitive paper 2.5m and 3.1m off the ground located at the centre of the tree.

Figure 9: The results from the fourth test

We saw an improvement in these results however there was still a delay in the nozzle activation/ deactivation. Therefore, the GPS to nozzle distance was increased in the Raven software.

Test 5

The fifth test was also carried out at 6km/h, the distance from the GPS to the nozzles was also shortened by 200mm (from the original measured setting) to make the nozzles turn on earlier with respect to the mapped location. The water sensitive paper was placed -700, 500, 700 and 900 mm from the centre of the tree, with extra water sensitive paper at the centre of the tree 3 meters from the ground.

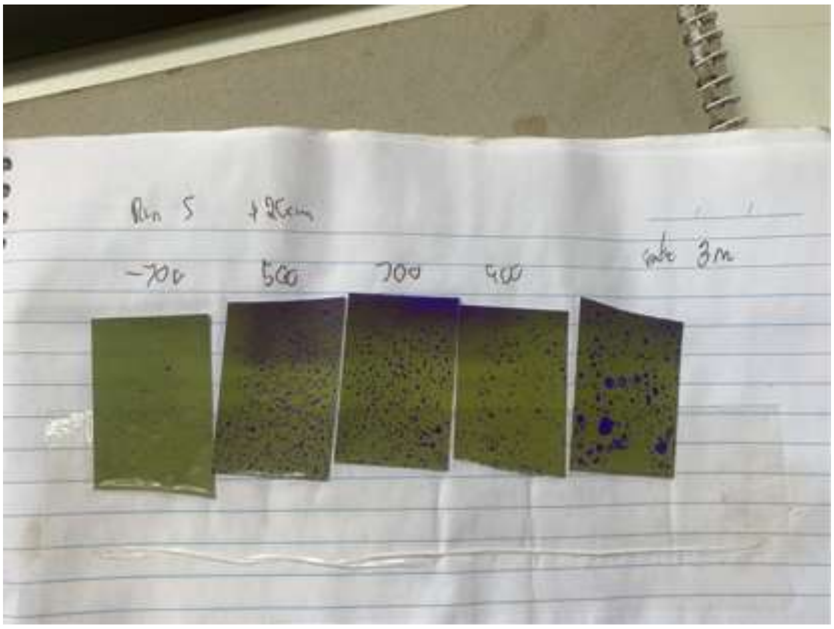


Figure 10: The results from the fifth test

These results were better and to the naked eye it looked very accurate. However, the distance to the GPS from the nozzles in the Raven Software was shortened again.

Test 6

The sixth test was also carried out at 6km/h, the distance from the GPS to the nozzles was also shortened by 300mm (from the original measured setting) to make the nozzles turn on earlier with respect to the mapped location. The water sensitive paper was placed -700, -500, 500, 700 and 900 mm from the centre of the tree.

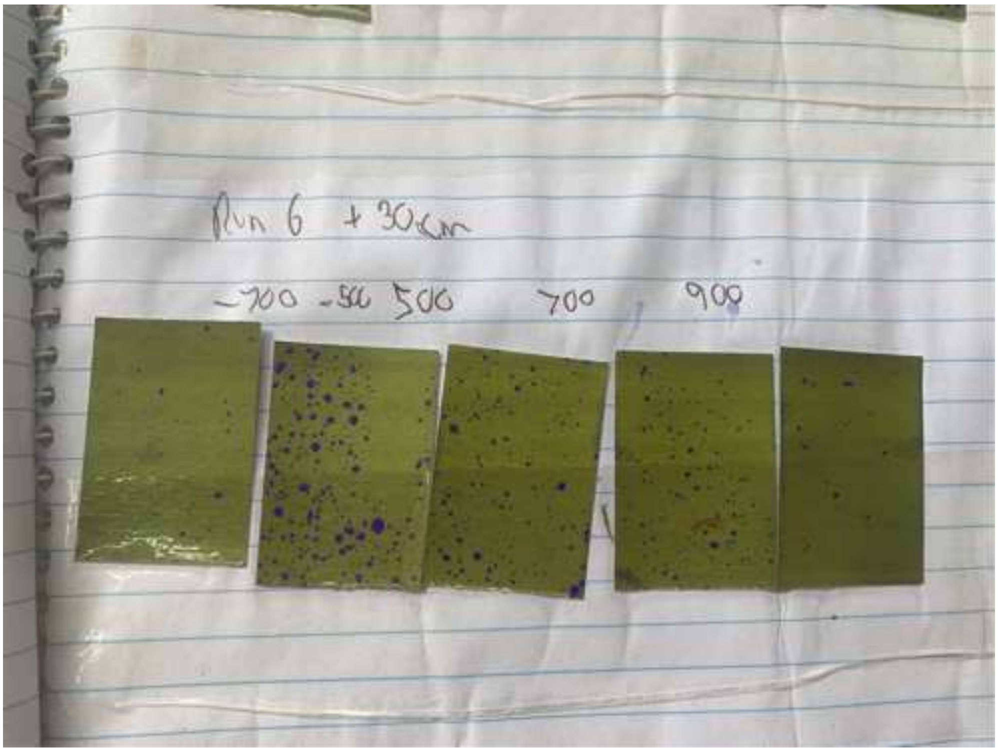


Figure 11: The results from the sixth test

This test showed the results we were looking for, with around 100mm accuracy to the mapped location which is what we saw with the fence line tests.

Test 7

We were happy with the previous results and as there was a slight breeze, we decided to try the next test from the opposite direction, previously we had been heading mostly south so for this test we were heading mostly north. The distance between the GPS and nozzles in the Raven software was left at 300mm shorter than the original setting. The water sensitive paper was placed 900, 700, 400, -400, -700 mm and an extra sheet down very low 900mm from the centre of the tree.

Figure 12: The results from the seventh test

These results brought us back to over 200mm accuracy, this was due to the wind so for the next test we brought the distance back slightly and tested it going south again.

Test 8

The eighth test was carried out at 6km/h and heading toward the south again. The distance between the GPS and the nozzles in the Raven software was shortened to 150mm shorter than the original setting. The water sensitive paper was placed -700, -400, 400, 700 and 900 from the centre of the tree.

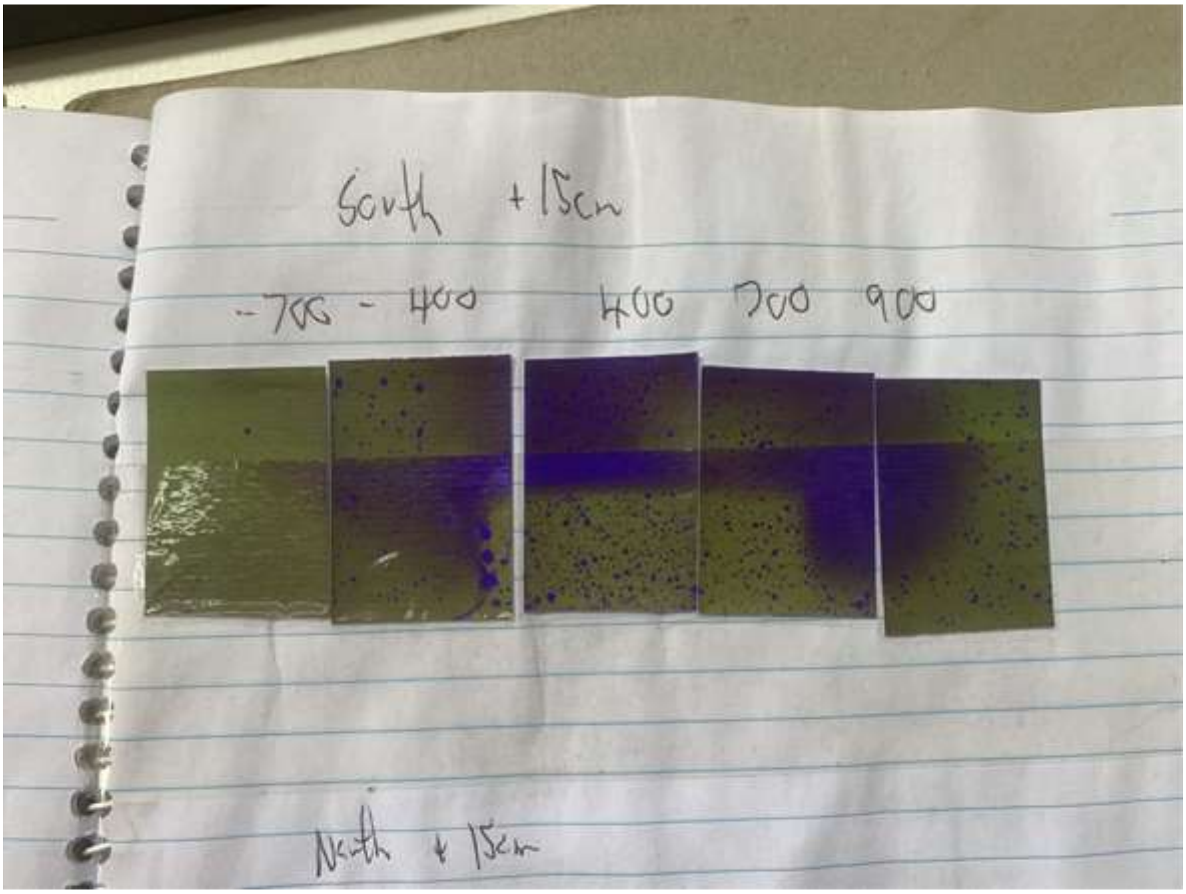


Figure 13: The results from the eighth test

The results were as expected, the nozzle activation and deactivation was a little late, due to the wind.

Test 9

The ninth test was carried out using the same settings, speed and water sensitive paper setup.

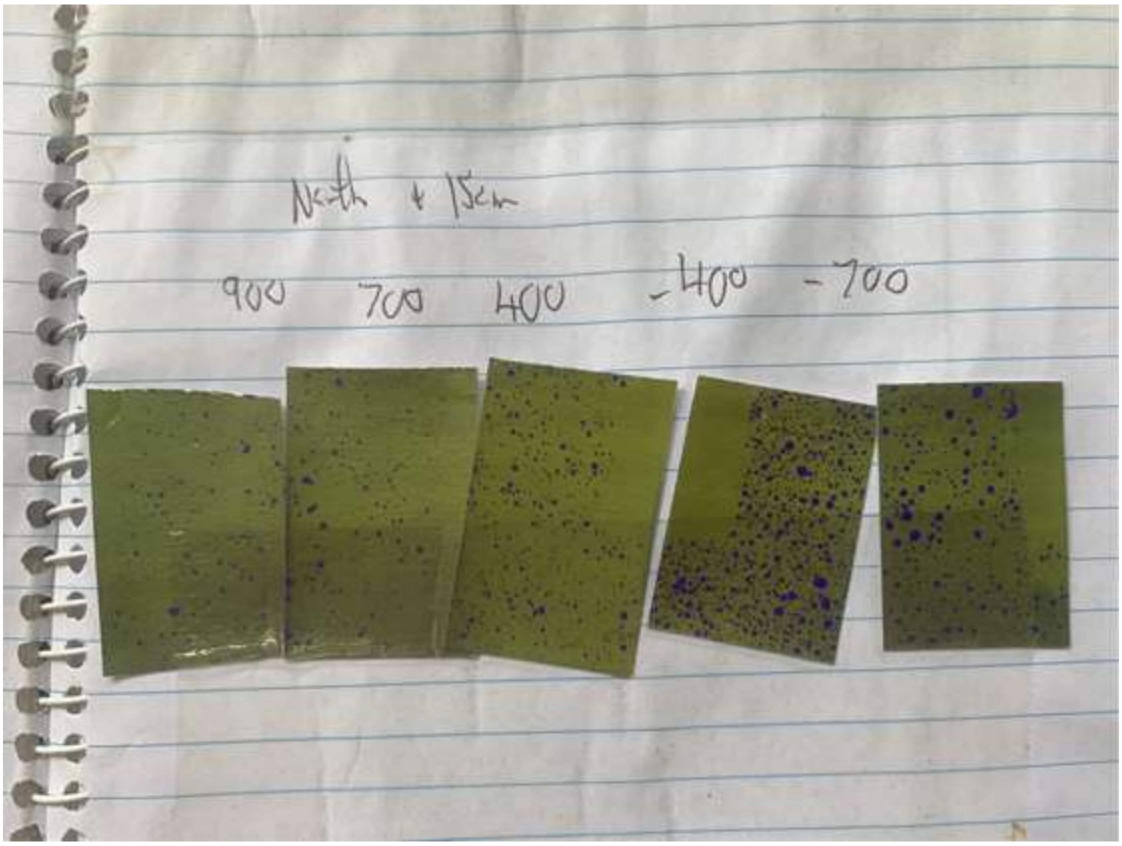


Figure 14: The results from the ninth test

The results were also as expected, the nozzle activation and deactivation was a little late. This lead us to the conclusion that the results we saw in the fenceline test were comparable in the orchard. We could have good coverage throughout the targeted tree with about 200mm of overlap in slightly windy conditions.

Test 10

The final test was using the same settings, it was designed to test the consistency and accuracy of the sprayer in the toughest scenario. We made a prescription map that only sprayed every second tree on both sides. Six trees in a row had water sensitive paper pinned to leaves in the centre of the trees. Trees 2, 3 and 4 also had a piece of paper put in the row behind them to see how much chemical would be going through the trees. The results are displayed below and are as expected with some chemical going to the next row over through tree 4 with less foliage.

Figure 15: The results from the tenth test

2.5 Commercialisation

After the rigorous testing and feedback from growers and agronomists, it is clear there is a market for variable timing of application primary thinning in conjunction with the flower stage detection system. This season the sprayer design was focused on commercialisation, using common ”off the shelf” components and documenting the build procedure. This build procedure has been shared with Silvan, to ensure feedback was accounted for when building the sprayer used for this testing. The simplicity of the design and the industry guide will make it possible for anyone with some sprayer experience to update the plumbing and install the Raven control system. This guide also outlines the method for setting up the software parameters in the Raven display and how to load in a prescription map that is generated using the Decision Support Tool. The industry guide to integrate the Raven Hawkeye control system with the silvan airblast sprayer is attached in appendix.

Appendix 2 - Autonomy in an orchard

This work package is developed in-kind by SwarmFarm Robotics.

Figure 16: SwarmBot Papa running in the Orchard

SwarmBot Papa was used to mow orchard blocks in Batlow NSW in 2021. Operating in 3.5m wide rows with a 2.45m Ben Wye slasher. The SwarmBot was customised to suit orchard conditions, with an increased turning circle, smaller lug tyres for increased torque in the rough terrain of the Batlow region and fitted with a high precision GPS for improved position accuracy within an orchard. Data was also collected using the on-board obstacle detection cameras to help build out a viable solution for robust safety in an orchard environment.

Figure 17: GIS maps generated for the orchard at Batlow NSW

Demonstration of supervised autonomous traversal of several orchard rows with SwarmBot

SwarmBot was able to successfully traverse between orchard rows and different orchard blocks. Papa is limited to a 2.7m turning radius, which means that a skip-row pattern was needed to be established so the machine could easily turn in/ out of each orchard row. This is a common approach used by farmers when spraying / mowing the orchard.

Demonstration of autonomous mowing of a block with SwarmBot. Report on cost/benefit analysis of autonomous mowing in orchard

SwarmFarm has successfully demonstrated autonomous mowing within a few orchard blocks in Batlow NSW. Papa successfully operated in both 3m and 3.5 row spacing's.

After a few trials it appeared that the safest operating speeds for an autonomous mower within an orchard is around 6km/hr. In a 3.5m row orchard, the robot is able to achieve around a 1.5ha / hr mowing rate. Autonomous machines can operate 24 hours a day, meaning 36 hectares a day could be completed. In some situations the grower will offset the mower to get closer to the tree bases as well as for different spaced blocks. In this situation the machine would have to drive the same path twice, offset to the left, then to the right. This method would half the number of total hectares done for the day. Having an autonomous robot mowing unsupervised frees up the grower to get on with other tasks around the orchard rather than being stuck in a cab all day.

Appendix 3 - Flower Stage Estimation

The following are the upgrades that were undertaken during the 2021 year. The main focus was robustness and speed of the software as well as developing the full system pipeline for making the process of data collection to spraying the application map as smooth as possible.

Figure 18: Example usage for the Apple Snapper

Software

The software for the collection rig was refactored to focus on speed and reliability. Software was developed to more accurately trigger the cameras at exactly the right locations when driving down the rows without the need for row end points. This guaranteed that the location of every image captured and processed was correct to give the most up to date information to the Decision support tool.

User Interface

The User interface was also refactored to make collecting data much easier for the growers. Live images along with the processed output were streamed to the web-app in real-time allowing the grower to see what the collection rig was capturing immediately. This gave confidence to the growers that the values the algorithms were outputting were accurate and consistent.

Upload to Cloud

Both Collection rigs have the ability to automatically upload output maps at the completion of each scanned block. Standard Shapefiles and geoJSON file formats were used to store the collected data. The data was recorded to file in real-time as the images were processed, limiting the loss of data if the device lost power for any reason.

Hardware

This year the hardware side of the flower detection unit was improved, consolidated and finalised into a commercial ready and scalable product.

The structural aspect is made from laser cut and folded steel, all designed and modelled on CAD programs to produce workshop drawings. This means the components can be accurately and cheaply mass produced anywhere in Australia or across the world. The structural components have been designed to bolt straight onto a stock standard Polaris Ranger, and with the modification of 2 parts this could be adapted to suit any side by side on the market. The overall design is quick to fabricate and install, embracing a modular design to quickly installed or removed by one person. Even when the flower detection unit is installed on the side by side, there is no compromise on everyday use, with the exception of slightly reduced cargo space. The whole unit is water and weatherproof and built to withstand the rigorous environment of the orchard. Wet, hot or dusty conditions or impact from branches have no impact on the performance or longevity of the flower detection unit.

A 3D CAD model of the final design

The wiring circuit was made by Harness Master in Maitland NSW. It is documented in electrical schematic drawings suitable for mass production. Installation is simple and quick, only needing to hook up to the side by side battery and 2 switches to turn on the computer and the lights. This again means someone without any engineering or electronics experience could easily assemble the electrical components of the flower detection system.

Structural Frame

The unit had to be designed mainly around the position of the cameras. As the cameras are used to capture images of trees that are over 4m high in rows that are 3.5m wide it was important to have the cameras located as far from the tree they are capturing, and as close to the centre as possible. This meant the cameras had to be located around 2100mm from the ground, and as close to the centre of the data collection rig as possible. Once the ideal position of the cameras were found, the lighting setup was designed to be compact. The strobe lights were pointed at the top and bottom of the area being photographed, this created the brightest, most consistent lighting across the tree.

Lights

The final selection was the Phoxene sx-3 strobe light. Strobe lights allowed us to maximise the limited electrical output (40 amps) of the side by side platform the system was designed for. The strobe lights are much brighter than common flood or spot lights. This increases the quality of the lighting which allowed us to travel at greater speed and capture crisper images, and collect consistent data during the daytime. The strobe light only ‘pulses’ for .00025 seconds each time the camera triggers an image. The factory camera software is used to trigger the lights which is a method widely used in machine vision. This means the simplicity of the system is maintained but the quality and variability of the environments it can be used in are vastly improved. Increasing the brightness of the lights meant this year the daytime data was much more consistent. In previous years, the lighting array was not bright enough to overpower the sun. This meant the output from the algorithm had some variability due to the overexposure of images looking into the sun.

The lights are not waterproof so a waterproof enclosure was developed that included diffusers for the lights. This is used to reduce hotspots in the images (areas of overexposure where the clusters cannot be counted). Two lights are used for each side of the vehicle, one points at the tops of the tree and one pointing at the bottom of the trees which gave the brightest and most even lighting across the orchard blocks we worked in.

Camera enclosures

The cameras used were not ip 68 rated, therefore additional camera enclosures were used to protect the sensors and the lenses. The camera enclosures are much lighter and easier to remove/connect to the flower detection system due to the M12 connectors than the orca enclosures used last year. The CEI Machine Vision Camera Enclosure 55m Series Round were brought in from the USA due to their compact design and price.

The CEI camera enclosures used in 2021

Final System Components

As reported in the previous sections a complete solution for producing flower stage maps was developed that could:

- Capture full height images of every tree in an orchard.

- Process images in real-time travelling at 10km/h.
- Get live-stream images and processed data to the Control Interface.
- Process multiple blocks in any order and any row-width.
- Instantly upload outputted data to the Cloud, ready to view on the Decision support tool.

The final parts list is as follows:

- Laser cutting and folding list:
  - 2x 50001
  - 1x 50002
  - 1x 50003
  - 6x 51000
  - 1x 51003
  - 1x 51004
  - 1x 51005,
  - 1x 51006
  - 2x 51007
  - 1x 51008
  - 1x 51009
  - 2x 51010
  - 2x 51011
  - 4x 51012
  - 1x 1502
- Ebox enclosure: Pelican case BG057032032.
- Wiring harnesses:
  - HM-SF-AS2-01
  - HM-SF-AS2-02
  - HM-SF-AS2-03
  - HM-SF-AS2-04
  - 2x HM-SF-AS2-05
- Strobe lights: 4x Phoxene sx-3 Harsh.
- Computer: Jetson Xavier - NRU-120S.

- Cameras: 2x FLIR Blackfly S (BFS-PGE-88S6C-C).
- Camera Lens: 2x Fujinon FUJCF8ZA-1S
- Camera Enclosures: 2x CEI EN-38R-A1-82.
- LiDAR: Velodyne VLP-16. $6780 OR SICK LMS111-10100.
- GPS: Novatel Smart7 + Relay7-400 radio.
- Relay PLC: IFM CR0431.
- 4G/WiFi Router: Teltonika RUT240-LTE.
- 4G/WiFi antenna: John Deere PFA10882.

Appendix 4 - Decision Support Tool

Website

Features

Accessibility and time to interaction were the two goals that influenced how the final decision support tool would look. Considering this it was decided that a website was the best option as opposed to a QGIS extension or a Windows App. A website allows the data to be accessed by anyone with a device connected to the internet and offers are large amount of custom user experience and interactivity. The key features that the Decision Support Tool Website offers are as follows:

- Access to all collected data. Figure 21(1)
- Can toggle between Top, Bottom, or Average for each tree. Figure 21(2)
- Change between Intensity, Stage, and Spray Map visualisation. Figure 21(3)
- Dynamic colour scales depending on Intensity or Stage. Figure 21(4)
- See all previous data collected for current Block 21(5)
- Change the cutoff for percentage past the selected stage. Figure 21(6)
- Visualise average stage distribution for whole block on line chart. Figure 21(7)
- View all data collected on a map with Satellite and Normal maps. Figure 21(8)

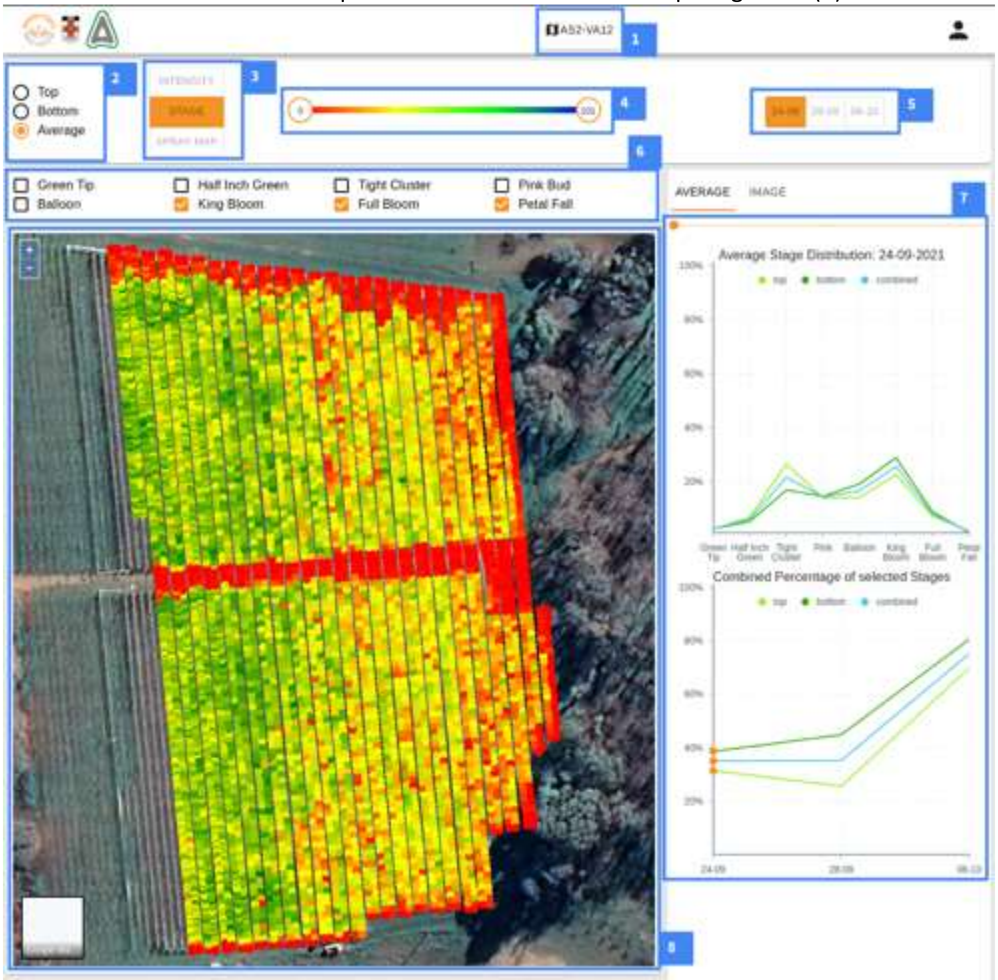


Figure 21

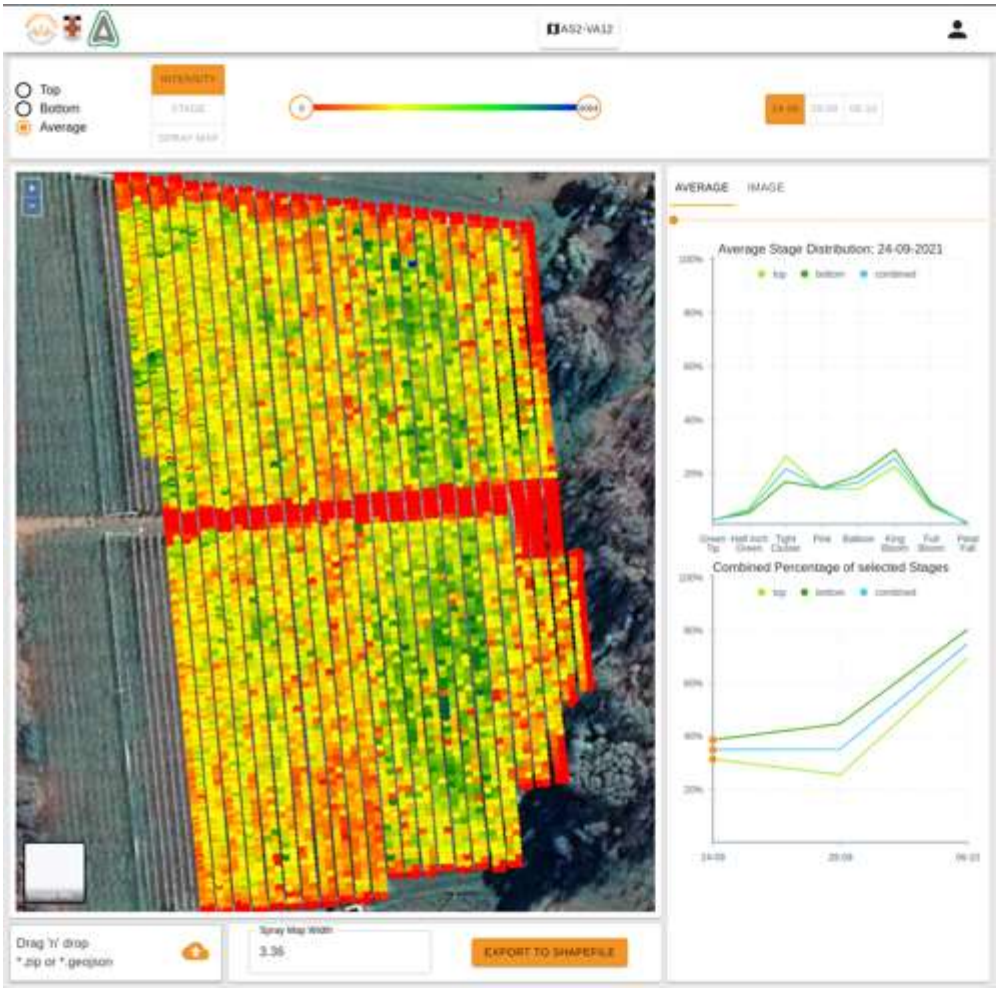


Figure 22

Insights

Flower load on a tree is an important metric to a grower in determining the overall spray strategy. The collection rig analyses the top and bottom sections of every tree and is able to detect white flowers, pink buds, and green tips and output an intensity value based on this data. These intensity maps can be used to quickly see which sections of the orchard block are producing a heavy load of flowers. This can be shown in Figure 22 where the areas of green and blue are much heavier than the areas in the red and yellow. One of the driving factors in determining when to spray an orchard block with chemical thinner, specifically ATS, is what flowering stage each bud is at. Our algorithms categorise the different stages into 8 categories; Green Tip, Half-inch Green, Tight Cluster, Pink Bud, Balloon, King Bloom, Full Bloom, and Petal Fall. This means that there is a key window of when the spray application applied is effective at a tree by tree level. For example an agronomist may count all buds on a tree and count 200 buds at or below Balloon stage, 100 buds at King Bloom, and 100 at full bloom. This means that 50% of the buds on the tree are at or past the King bloom stage. As we are able to accurately assess the top and bottom of every tree and return a percentage value for each stage in each section, we can calculate this percentage pass King Bloom, or for any stage, for the whole block at a tree by tree level. From this data you can quickly see what flowering stage each tree is at across the whole block. This can be seen in Figure 21 where the colour scale is a percentage from 0 (Red) to 100% (Blue) past and including King Bloom showing that there are large areas of the block past 50% King bloom (green and blue). Both these data visualisations can help the grower understand how heavy the individual trees are with flowering buds as well as how far progressed they are in their flowering stage. The more data you gather during the early stages of flowering, the more insights you get in seeing how fast or slow the whole block or areas of the block are progressing. Using this data along with weather data allows the grower to make more informed spray decisions of when, where, and how much they need to apply for every tree in the block.

Spray Map Output

Being able to see flower intensity and stage information for an entire block at a tree by tree level is a great resource on its own in helping the grower make informed decisions in regards to how they treat their block. This project takes it a step further and allows the grower to analyse and output a spray map that can be loaded into a compatible sprayer and actually treat each tree individually based on the data collected. The grower is able to use a slider as shown in Figure 25 to choose which sections (Top and Bottom of every tree) they want to spray or ignore. This slider filters out every section that falls below the select percentage of past King Bloom. In other words, in Figure 25 the grower has select every section that has at least 70% of its buds at or past King Bloom, and wants to apply a water rate of 800L/ha for the top and 1200L/ha for the bottom. This level of application means the grower does not have to change water rates or turn on and off sections manually based on the maps, but can rely on the sprayer software to turn on and off at the exact position it needs. The Sprayer Software is able to use the same GPS as the Collection Rig to achieve this accuracy allowing for very precise application.

Appendix 6 - Airblast Sprayer Industry Guide

Airblast Industry Guide

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Contents

1 Introduction

This guide has been developed by SwarmFarm Robotics together with Silvan Australia and Raven Applied Technology to pass on the technical expertise that has been developed over the past 3 years. A series of sprayers have been developed, built and tested in conjunction with the flower stage detection and mapping technology as part of the Hort Innovation project. This guide will outline in detail the method to update a new or used Silvan Airblast sprayer with a Raven Hawkeye control system to be able to execute the prescription maps generated via the Flower stage detection technology. Specifically this guide will be based on using a new stock standard Silvan Supaflo 2000. This may be a specific guide for one type of sprayer and control system, however this method can be used as a general guide to update various types of orchard sprayers.

2 Parts List

2.1 Description

This section will outline every aftermarket part used on the sprayer to update it with the Raven control system. Lots of these parts are interchangeable with common plumbing fittings. The only important parts that should not be changed unless they are substituted with parts that have the same input/output signal types are the flow meter, dump/bypass valve, regulator control valve and the pressure transducer.

2.2 Silvan

This is the exact shopping list used to build the airblast sprayer SwarmFarm used in testing at Batlow during the 2021 flowering season. This list excludes the stock Supaflow 2000 Airblast orchard sprayer.

Part Name	Amount Needed	Part Number
Conveyor	1	D99-110
Boom Recirculation Valve (dump valve)	1	G8388015
Proportion Control Valve	1	G8386010
Wolf Flow Meter 5-100L/min	1	46263A0
Teejet Nozzle Body Quick	24	QJ8369-NYB
Blue Hollow Cone Ceramic EQV ATR-28	24	HCC050
$\frac{1}{4}$" M BSP to $\frac{1}{4}$" F BSP (20mm long) Adapter	24	474-050L
$\frac{1}{4}$" M BSP to $\frac{1}{4}$" F BSP 90 degree elbow	24	474-130
$\frac{3}{4}$" F BSP to $\frac{3}{4}$" F BSP 90 degree elbow	4	474-156
$\frac{3}{4}$" M BSP Hose Barb Suit 1" Hose	4	G8001205
$\frac{3}{4}$" F BSP to $\frac{3}{4}$" M BSP 90 degree elbow	2	474-158
1" M BSP Hose Bard suit 1" Hose	8	G8001252
1" Tee piece FFF	2	G8026251
$1\frac{1}{4}$" Tee piece FFF	1	G8026301
$1\frac{1}{4}$" BSP FF 90 degree Elbow	2	G8019301
$1\frac{1}{4}$" BSP M Hose Barb suit $1\frac{1}{4}$" Hose	2	G8001303
$1\frac{1}{4}$" (32mm) Black Chem Hose	5m	186-32M
1" (25mm) Black Chem Hose	10m	186-25M

2.3 ARAG

The is the list of ARAG part not available through Silvan that can be purchased through most Spray parts suppliers. Again this list can be substituted for other parts and other configurations can be used.

Part Name	Amount Needed	Part Number
463 series inlet ($1\frac{1}{4}$" BSP M)	2	463 000.050
463 series outlet ($1\frac{1}{4}$" BSP M)	2	463 000.150
$1\frac{1}{4}$" BSP M Hose Barb suit 1" Hose	2	1032525
$1\frac{1}{4}$" BSP F Hose Barb suit $1\frac{1}{4}$" Hose	2	100533

2.4 Raven

The Raven system we used was a Hawkeye Nozzle Control system with a CR7 display. Some of the wiring used on this sprayer were custom made to suitable length for this specific sprayer (with Raven Industries permission). This system could be substituted for Hawkeye 2 and a Viper 4 display very easily, these are newer and more common control systems avaliable from Raven.

Part Name	Amount Needed	Part Number
Hawkeye generic cabling for pull type sprayer (option 1)	1	
CR7 Field Computer	1	117-2295-001UN
Hawkeye Nozzle Control Valve	24	063-0173-672

3 Overall Design

The main idea behind the redesign of the Orchard sprayers to include the Raven Hawkeye control system is to turn sections on and off much faster than regular section control valves, to increase the accuracy of application. The Raven Hawkeye control system uses Nozzle Control Valves (NCVs) to switch the flow of the liquid on and off instead of the regular section valves. These NCVs utilise PWM (Pulse Width Modulation) technology which pulse at 30 Hz, which means they can open and close 30 times per second. This is compared to regular section valves which can take up to 2 seconds to open or close. The NCVs are also located at the nozzle, so there is much less delay between when the valve is switched to on and the chemical arriving at the nozzle than conventional section valves. The nozzle control valves can also pulse at different duty cycles, allowing the desired rate to be applied at the correct pressure at slower speeds. For example if you were travelling at half the speed your nozzles are suited for, the Raven system will pulse the NCV's at 50%, maintaining the correct rate and pressure.

The Raven Hawkeye system also uses a "Boom Recirculation Valve" which is a valve that opens when all the nozzles are turned off. This allows the system to maintain a flow rate similar to when the nozzles are on, the effect of this is the pump/control valve has to spool up and down less and less often which increases the accuracy of the rate applied out of the nozzles. Below (Figure 1) is a plumbing diagram outlining the basic setup of the upgraded sprayer.

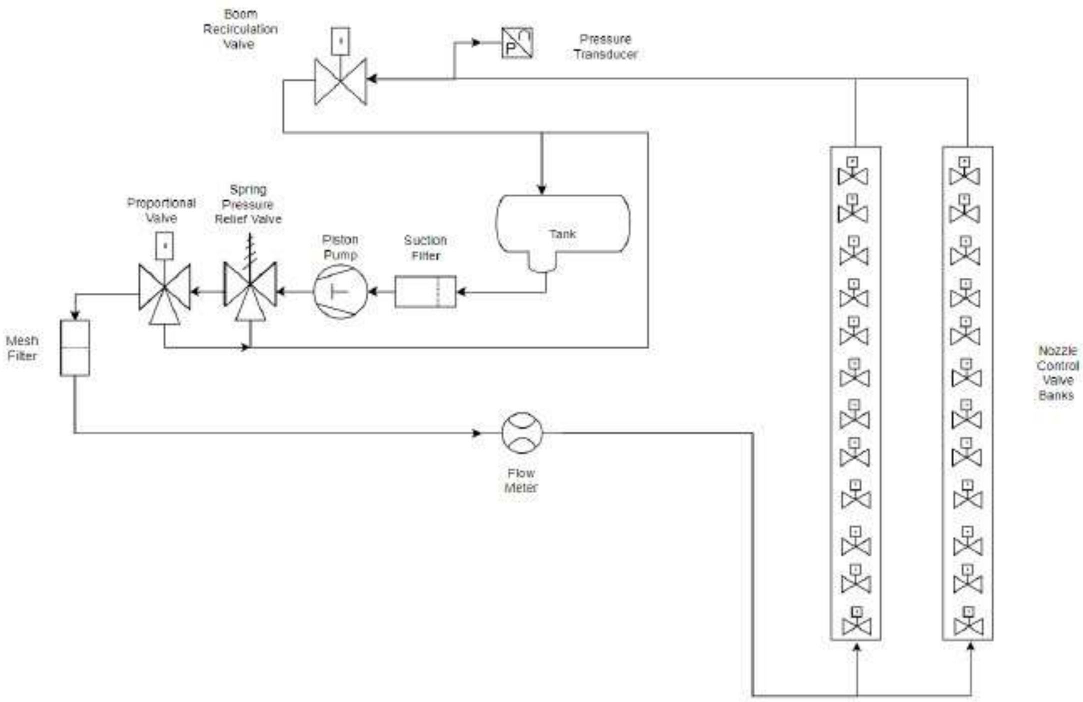

Figure 1: Sprayer Plumbing Diagram

4 Build Procedure

4.1 Removal of the Silvan Parts

Remove all the Silvan control system located above the pump. All will be not needed except the manual pressure relief valve and the filter. The control valve will have to be replaced with the faster 7 second Proportional control valve to ensure changes in rates will be followed quickly. The Section control valves will not be needed, however the dump/ bypass valve will be moved to the end of the circuit. The following image (Figure 2) shows the stock Silvan control bank.

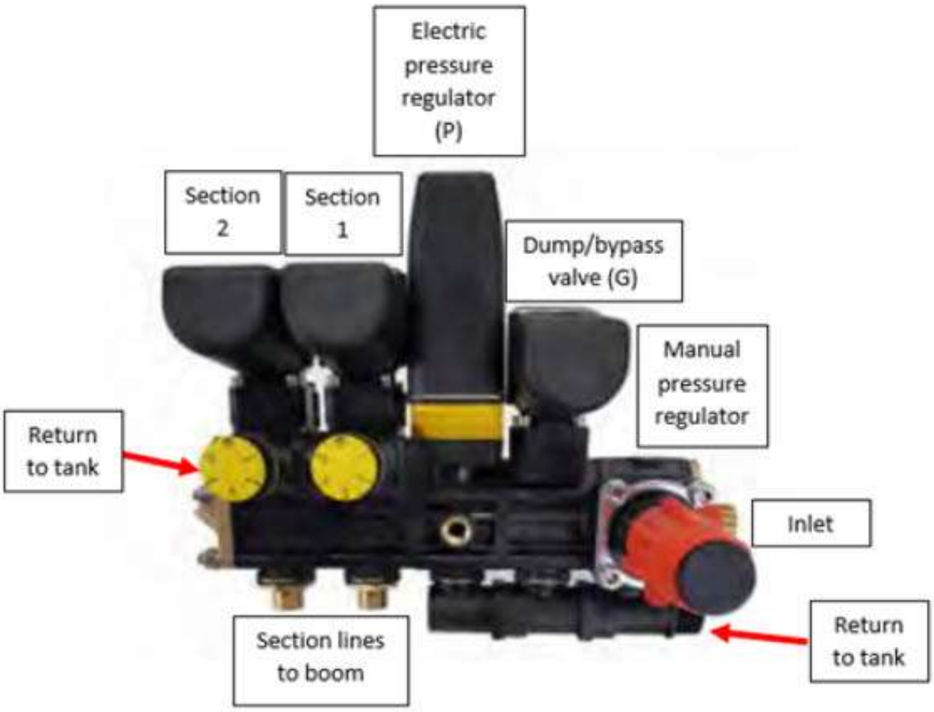

Figure 2: Control System used by Silvan

4.2 New Raven Control System

As the Raven Hawkeye control system uses individual nozzle valve the section control valves are not needed. The new control bank will incorporate a manual pressure regulator (as a safe guard), the electric proportional control valve to regulate flow/pressure in the system, a fine mesh filter and on the return line a boom recirculation valve (or dump valve).

This method allows the system to maintain pressure and flow to the nozzles, as the dump valve only opens when all the nozzles are turned off. This in turn then allows for much more accurate application of chemicals in regard to the rate and accuracy of the location of application. Each nozzle can turn on and off or 'pulse' in a fraction of the time that a section control valve can open or close, allowing for much more accurate section control at higher speeds.

Figure 3: Control System now used

4.3 Plumbing

Remove the original section lines that feed chemical to each side. The outlet from the new control bank leads to the spray bars via a flow meter which fits conveniently inside the chassis of the Supaflo 2000. This hose is 1 ¼" black chemical hose and runs to the back of the sprayer where it splits to each side. This hose goes into a T piece under the PTO shaft at the start of the fan where it splits into 2 1 inch hoses to go to each side.

Figure 4: Flow meter located inside the chassis rail

Figure 5: Pressure side T piece, under the fan bearing block

4.4 Original Spray Bars

The original spray bars can be removed to make way for a conveyor. The conveyor is added to improve the accuracy of the spray delivery and to concentrate the airflow to the selected part of the trees. The conveyor is attached to the sprayer fan frame by M6 bolts on the front and rear of the conveyor.

Figure 6: Conveyor attached to the Silvan sprayer fan

4.5 Fitting out the conveyor's spray bars

First step is to remove the factory nozzles, this should leave a ¼ bsp female thread at every nozzle location. Using the ¼" bsp MF 90 degree elbows and the MF ¼" adapters you should then be able to attach the teejet non drip quick release nozzle body. The non drip cap is then removed and the Raven Nozzle Control Valve (NCV) is put in its place. Hollow cone ceramic (HCC) nozzles with quick release teejet nozzle caps were used in this application.

Figure 7: Assembled elbow, spacer, nozzle body and nozzle cap

Figure 8: Assembled nozzle and NCV

Each spray bar also needs an inlet and an outlet connection to 1" black chem hose. The ¾" BSP caps were removed from the top of the new spray bars and 2 elbows were used to reroute the chemical back down to a tee piece where it is then plumbed back to the boom recirc valve at the front of the sprayer.

Figure 9: Fully Assembled Conveyor

At the bottom the original elbows are used along with an MF ¾ to 1" adapter and a 1" hose barb to create the inlet for the spray bars.

Figure 10: Bottom input to spray bars

4.6 Return Line

The outlets from the top of the spray bars join in the middle at the bottom of the conveyor at a Tee piece. A single return line then follows the inlet line back to the control systems at the front of the sprayer. The return line then enters the boom recirc valve, this will allow the pump to continue circulating chemical through the system when all nozzles are turned off. The boom recirc valve also houses the pressure transducer.

Figure 11: Boom control with Incorporated pressure transducer

4.7 Hawkeye Controller

The raven Hawkeye uses a single small controller, on this sprayer it is mounted on the rear, between the fan and the tank. A small plate was made to hold the controller which is secured to the sprayer by 2 holes that were drilled and tapped with M6 thread.

Figure 12: Hawkeye Controller

4.8 Wiring - Hawkeye generic cabling for pull type sprayer (option 1)

Generic wiring harnesses can be used along with some basic extensions to reach the front of the sprayer. The only sensor cables that are needed are the flow meter, control valve, boom recirc valve and the pressure sensor. Extensions may have to be made for these if the generic wiring harness does not reach. The nozzle harnesses in these photographs are custom made to suit the sprayer however generic ones will also do.

Figure 13: Rear view of fully assembled conveyor

Figure 14: Nozzle wiring harness

The "ISO/Nozzle power extension" cabling that runs from the back of the tractor to the Raven Hawkeye ECU sits inside the left side chassis rail. The only other cables that run from the ECU are to the nozzles which go straight from the bottom of the ECU, between the fan and the tank to the conveyor. There is extensive documentation for the installation of Raven Hawkeye systems on broadacre sprayers which can be easily adapted to suit the plumbing setup of an Air Blast sprayer like this.

4.9 Raven Software Setup - UT

There is also extensive documentation for setting up a Raven Field Computer to work with a Raven Hawkeye system. The following will show the setup the worked for this Supaflo 2000 and CR7 Raven Field computer.

The Field Computer should automatically pick up the Hawkeye ECU on the sprayer the first time it is hooked up together. The ECU should then pick up each individual nozzle control valve. The screen on the Field Computer should look something like this at this stage:

If the total and left nozzle counts are correct proceed, otherwise refer to the Raven Hawkeye documentation for troubleshooting.

Set the Applicator type to Sprayer and continue. Enter the nozzle spacing on the next page. To suit the maps the Swarmfarm Decision Support tool creates, the sprayer needs to match the width of the maps, so the nozzle spacing must be the total width divided by the number of nozzles. This corresponds to having the right number of nozzles turning on and off when spraying the top and bottom sections of trees separately. For the 24 nozzle

Figure 15: First screen of Hawkeye calibration setup

Figure 16: Select the applicator type: Sprayer

supaflo 2000 we entered a nozzle spacing of 16 centimeters is used.

Figure 17: Input Nozzle Spacing

The next step is to select the nozzle size installed on the sprayer. We used HCC050 nozzles, the configuration of this sprayer does not incorporate a Bypass Tip so leave Bypass Tip Size as NA.

Figure 18: Select the tip size on the sprayer

Next the Raven system will find the location of each nozzle in regard to the top and bottom of each side. This is what auto indexing means.

Figure 19: Start Auto Indexing

Leave "Enable Fence Rows" unchecked.

Figure 20: Do not check fence rows

Set the number of sections to 4. This corresponds to the top and bottom half of the tree on the left and right side. The Swarmfarm DST will output maps with 4 sections to spray each area of trees accordingly.

Figure 21: 4 section are used to execute the SwarmFarm maps

Set the width of each section to 96cm.

Figure 22: Set the section widths

Leave the boom offset as 0cm.

Figure 23: Set Boom Offset

Set the Valve Type as "Fast". A fast proportional valve is used in this setup, however a PWM hydraulic control valve has also been used on previous versions of this sprayer with success.

Figure 24: Select type of control valve

Set the pressure sensor range to suit the pressure sensor in the system (the Raven sensor that comes with the Hawkeye kit has a range of 0-250psi with is 0-1725 kPa roughly).

Figure 25: Select pressure sensor range

Fill out the details of the Flow meter installed on the sprayer. The following calibration values suit the Flow meter recommended at the start of this guide.

Figure 26: Flow meter specification

Set the desired target rate (this will only be used when not spraying using prescription maps).

Figure 27: Target rate

The max pressure of the Hawkeye Nozzle control valves is 550kPa, it is suggested to set the pressure to 500 kPa to allow for spikes.

Figure 28: Target pressure

After this the initial setup is complete. This sprayer can then be used as a regular airblast sprayer, the Hawkeye system will regulate pressure and rate like a regular spray control system with section control etc.

4.10 Raven Software setup - Machine Dimensions

The next step in the setup will input the dimensions of the tractor and sprayer. If the GPS is mounted on the Sprayer NOT the Tractor, just fill out the new configuration with the dimensions as a Self Propelled sprayer. If the GPS is mounted on the tractor create a new configuration for the tractor and sprayer dimensions. From the main menu select "Machine" and follow the steps.

Figure 29: Main menu with machine dimensions highlighted

Figure 30: Machine configuration page

Once the measurements of the sprayer and tractor have been input, you then have to "Mount Equipment" the sprayer. The controller will automatically pick up the configuration input in section 4.9, it will be called "Sprayer" and you wont be able to edit any measurements or details.

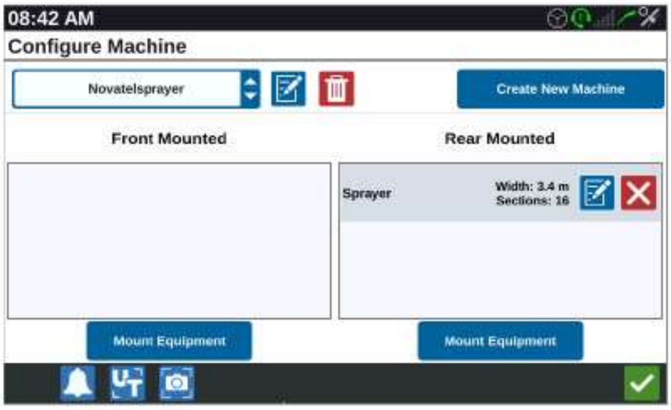

Figure 31: Mounting equipment on machine at selected dimensions

4.11 Raven Software setup - Prescription maps

The next step is to load in the prescription map. The way to import the prescription map from the Decision Support Tool website is to save the shapefile prescription map (and associated files) to a USB stick. This USB can be inserted into the back of the field computer and the files can be saved onto the field computer through the File Manager in settings.

Figure 32: File Manager screen with USB selected

Select the dropdown location menu that will be on Local and select the name of the USB you have inserted into the field computer, then select Prescription. The prescription map should then be able to be found in the list in the right side of the File Manager.

Figure 33: Prescription selected on USB

Select the file you want and hit the copy bottom and then the green tick. This will save the file to the field computer. Then select the green tick in the bottom right corner of the screen twice to return to the map screen.

Figure 34: Prescription map selected and copy button highlighted

From the map screen hit the field list button (highlighted below) and select or create your field.

Figure 35: Open the field list

Then select your job to continue or select the right arrow to create a new job. After you have created a new job select your prescription map, select the list button highlighted below.

Figure 36: Load in prescription map

Then select the dropdown menu that says "No Rx Map" and select your prescription map.

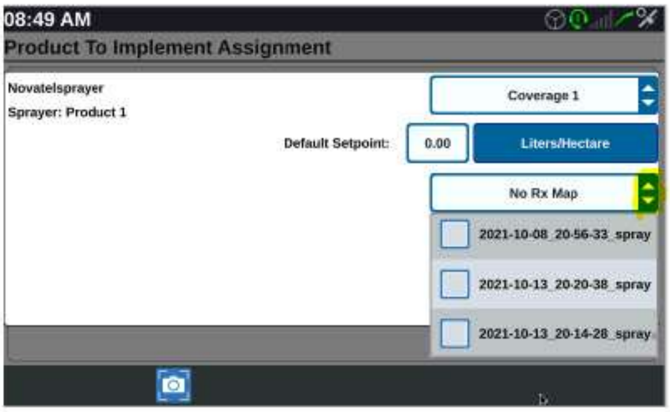

Figure 37: Selecting your prescription map

Then select the dropdown menu "Select Setpoint Column", this will determine the rate that is used in the prescription map. The Decision Support tool setpoint column is called RATE.

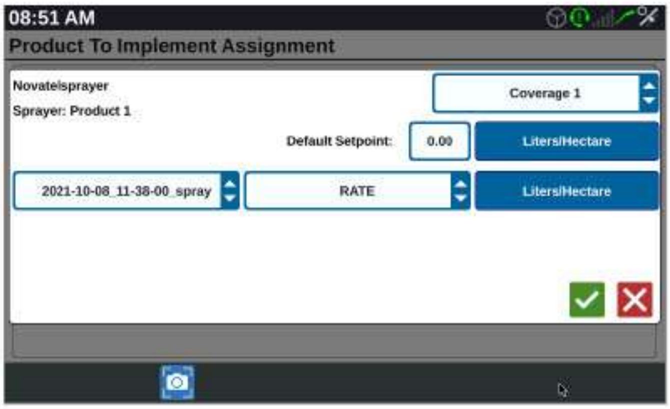

Figure 38: Selecting your prescription map target rate

Then select the green tick and proceed to the map. To turn the system on, press the red switch on the map screen, which will then turn green like the image below.

Figure 39: Main switch off

Figure 40: Main switch on

Then go to the UT, press the pump in the top right of the screen (the pump symbol), this will allow the control valve to work. The PTO can then be engaged to spool up the pump.

Figure 41: Open the UT

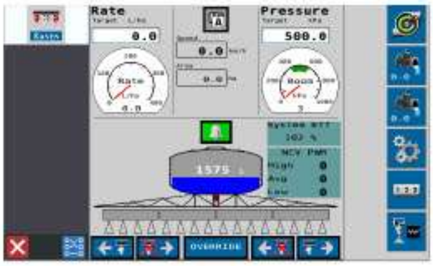

Figure 42: Activate pump control

Then hit the foot switch twice and the nozzles will active when entering the prescription map. You can now spray prescription maps.