Australian Government
Wine Australia

Flinders UNIVERSITY

Semi-Automated Undervine Slasher Development



FINAL REPORT TO WINE AUSTRALIA

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Abstract

Automation in vineyards is a necessity; however, there exist several challenges, such as harshness of vineyard unique environment which makes vineyard automation not a simple process to undertake. This project aims to develop a Semi-Automated slasher system which enable farmers to attain a better, faster, more cost-effective slashing with minimum supervision. The development of the smart under-vine slasher is a proof-of-concept design to show the feasibility of viticulture automation in a simple application. The design is successful in demonstrating this, proving further industrial automation may also be feasible.

Executive Summary

With the advent of the fourth industrial revolution, intelligent systems have been created to solve traditionally complex tasks [1]. As the viticulture industry in Australia generates over $13 billion annually and supports over 172 thousand jobs [2, pp. 14-27], Ledgard Pruning Systems in conjunction with Flinders University have determined that the development of a semi-autonomous under-vine slasher will continue to support and foster the growth of the Australian viticulture industry.

Although under-vine slashing technology is largely primitive, intelligent systems from a variety of industries have been analysed to guide the innovative semi-autonomous under-vine slasher's control system. In general, an intelligent control system functions in three distinct phases, a sense phase, plan phase and act phase [3, pp. 1-2]. The sense phase of the control system was developed utilising the mechanism produced by Ostojic [4]. An investigation was undertaken into the sensing mechanism's performance to ensure the reliability of the control system. It was determined that to increase system reliability, pull-up resistors had to be added to the membrane potentiometers used to detect vine collision to reduce the impact of noise. A LiDAR running in conjunction with Hector SLAM was used to measure system displacement instead of an IMU due to the increased accuracy afforded by the LiDAR.

The plan phase of the control system operates in real-time to create an ideal path for the system.

As the hydraulic actuator (which physically controls slasher head movement) is fed by a three-way valve at a constant flow rate, the act phase of the control system was developed as three-state on-off controller incorporating hysteresis. A hydraulic actuator was not made available for experimentation and as a result, the performance of the controller was tested utilising a dynamic mathematical model, replicating the response of the system in the possession of Ledgard Pruning Systems.

Each phase is then combined to create an intelligent, "smart" slasher that is capable of avoiding vines.

Introduction

The Australian wine industry generates over $773 million AUD from the sales of wine grapes for the Australian economy [2]. The importation and exportation of wines in Australia generates $4 billion per year, whilst the international and domestic tourism associated with vineyards and wineries exceeds over $9 billion per year [2]. The industry also indirectly and directly employs over 172 thousand people in Australia [2]. It is clear that the wine industry in Australia is extremely beneficial to the GDP of the country and provides socioeconomic stability for people employed not only in the viticulture industry, but also those in the hospitality and logistic industries to name a few, as well as the employees' families. As a result, it is imperative that the viability and long-term success of the wine industry is maintained and adapted to suit the ever-changing requirements of societal demand.

Potential threats to the success of the wine industry, include insufficient grape yields, utility pricing (water charges), soil erosion due to weed management, and poor-quality wines due to fungal infestation or other environmental causes impacting the quality of the crop. Weeds are of particular concern to agriculturalists from all industries, including wine producers, as they compete with target crops for space, shelter, thermal protection, water, and other nutrients [5]. Not only does this mean that profits are lost through decreased crop yield and the implementation of weed management solutions, but if weeds are rampant within fields, money is spent fostering the growth of these weeds when using soil additives and watering the target crop with the intent to maximise target crop quality. It is therefore apparent that an effective weed management solution needs to be utilised within the agricultural industry to increase the efficiency of crop growth.

According to Bekkers [6, p. 2], one method that has been widely used for weed control in viticulture is to plough under vines. That is, to physically disturb the earth and rip up the soil below the vines. Whilst this method is successful at removing weeds, there are several drawbacks associated with this practice [6, p. 2]. The drawbacks of this method include soil erosion, nutrient loss, and potential damage to vines.

Another method to remove crop competition is the use of herbicides. One of the most widely used herbicides in the wine industry is glyphosate [7, p. 255]. Glyphosate, whilst a very effective weed killer [8, p. 380], also poses significant health risks to people who handle it, spray it, or come into contact with it [7, p. 263]. It is currently unknown whether the use of herbicides during the growth stages of crops pose health risks to the consumer post-production, however, the health risks posed to those who handle it are significant enough to see it banned in some communities worldwide [9]. Additionally, the use of chemical herbicides reduces the quality of the final product and tamper with the ecological balance of the vineyard [8].

According to Chou [10, pp. 5-6], suitable selection of cover crops beneath the vines will result in a secondary crop that minimally competes with the target crop for water and nutrients, while continuing to compete with weeds. This offers an effective weed management solution that does not contain the drawbacks of the previously discussed solutions with one caveat – if cover crops are left unmanaged, they too will grow excessively and begin to compete with vines for nutrients, water, and sunlight. It is therefore necessary to manage cover crops, however, unlike weeds, cover crops do not need to be completely eradicated, allowing for less harsh management solutions.

Mowing a is a simple solution to keep cover crops at optimal height and mass. Mowing in a vineyard contains several operational challenges compared to other sectors, as vines occupy the majority of space

and are fragile enough that mowing can cause significant damage. While traditional mowing can still be used effectively in the inter-row spacing, there are limited solutions for removing the growth underneath the vines. Yet, it is vitally important that this undergrowth is removed to insure an optimal growth environment [11, p. 932]. The current solutions for mowing the vine undergrowth are either to manually mow them or using heavy duty slasher systems. If the vineyard is small enough, it may be reasonable to manually mow the intra-row vegetation. However, due to the amount of labour required, as well as the potential to seriously injure grapevines, this solution is only used as a spot treatment [12, pp. 10-11].

For larger scales, heavy duty slashers (mechanical impact systems) appear to be the most used option in the vineyards. Among existing mechanical systems, Ledgard's heavy duty slasher has been outperforming for many years. This system developed by Ledgard Pruning Systems utilises a welded bar that comes into contact with the vines, compressing a hydraulic cylinder. Once the pressure on the welded bar is removed (by passing the vines), the hydraulic cylinder expands, pushing the blades back to their original position [4, pp. 7-8]. This design is cost-effective and fast to operate – reaching speeds up to 6km/hr. However, as noted by Ostojic [4, pp. 7-8], a significant downside of this system is that it will destroy vines that do not generate enough force to actuate the welded bar, which makes it unsuitable for use on younger vines. Also, due to its simple mechanism, there is always a significant portion of crop remaining, shielded by the deflection of the vine trunk.

To attain a better finishing, Marlborough Tractor Services has implemented a different mechanism in their system. They use a circular rotary head as the cutting interface for their system. A rubber buffer is fixed around the blade's deck so that when it comes into contact with an obstacle, a frictional force is generated between the two and the head rotates around the obstacle [4, pp. 9-10]. This design is very simple and cost-effective, while also performing extremely reliably. The drawback of this design is that it relies on the circular rotary head colliding with the vines in order to rotate around it, which restricts the maximum speed of the system to 3km/hr, half the speed of the previous system [4, pp. 9-10].

To minimise the impact, Viticulture Solutions under-vine slasher utilises a smarter mechanical system in which a rotary head comes into contact with the vine, spinning the head until the next blade locks into place. The head is designed such that the arc between two blades is sufficient for any vine diameter [4, pp. 8-9]. This design is effective at reaching all plant matter, while still be relatively simple. The speed of this system is the primary downside, operating at approximately 4km/hr, limiting the effectiveness of this system on larger vineyards [4, pp. 8-9].

While mechanical impact systems are effective in their simplicity, there are common issues among them limiting their operational speed. Also, the excessive care required to not damage any vines while operating the system, requires hiring specialist drivers which leads to increased operational costs.

Further development to reduce the level of mechanical impact has been introduced by Fisher Australis through sensorizing the vine touch. Fischer Australis uses touch sensors mounted on the slasher such that when they come in contact with vines and posts, a hydraulic actuator moves the blades out of the way [4, pp. 6-7]. This system is very effective at avoiding all kinds of vines, as the sensors do not require much force. However, for the sensors to work effectively it is required to maintain a constant speed, approximately 4km/hr [4, pp. 6-7], which is the biggest disadvantage of this system. On top, the open loop nature of this system, also, reduces the area of plant matter reached due to suboptimal path planning.

Although the use of touch sensors demonstrated promising results in minimising the mechanical impact; it imposes new speed restrictions due to its current open-loop implementation. A possible solution to overcome this restriction is to incorporate the same sensors in a closed loop system. This allows separation of the sensing mechanism from the mechanical actuation, leaving the speed of actuation solely as a function of its mechanical (or electrical) power. By doing so, not only can the operational speed be modulated according to the situation, but also optimised plant matter area coverage would become achievable through path planning.

The main goal in this project is to develop a closed loop semi-automated slasher system that successfully fulfils the market requirements (not requiring a specialist driver, operating at modulated speed, and not damaging young vines, while remaining cost-effective). For such a system, it is important to reliably localise vines beforehand and execute continuous real time path planning, to be able to perform a closed loop modulated actuation around the detected vine. The benefits that such a system would bring to this sector would justify its market compatibility through more efficient performance, reduced crop damage and dramatically reduced labour cost.

Defining Case Study

As the goals of this project are centred around logic and control, an existing impact slasher system developed by Ledgard was chosen to be used as a case study in this project. The selected slasher system has already been thoroughly tested in the field, removing much of the R&D cost associated with developing a similar system.

Ledgard's slasher mechanism (seen in Figure 1) consists of a metal structure that rotates around a single point. The rotation is generated by the extension and retraction of a hydraulic ram as seen to the left of the arm (denoted as length S). The hydraulic ram in Ledgard's current design is connected to an accumulator. The ram is retracted while the slasher is incident with a vine, causing accumulation of hydraulic pressure in the accumulator. The accumulated pressure then returns the slasher deck back to its extended position as the system passes a vine. For controlled actuation, a simple modification to this design is required which will be explained in this section.

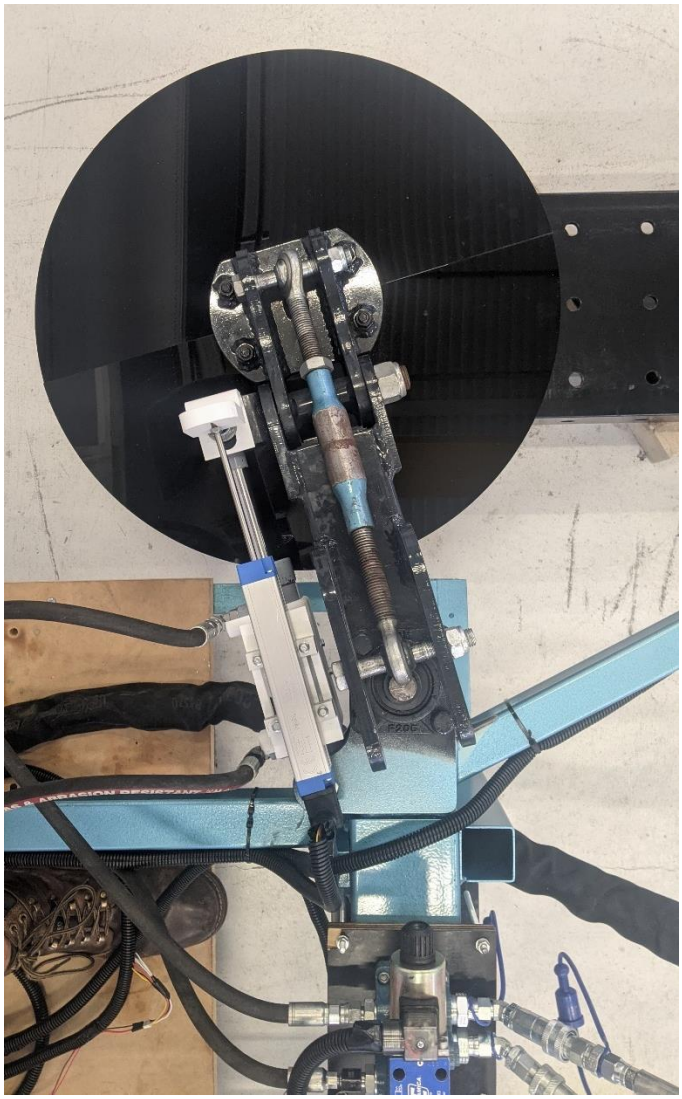


Figure 1 Slasher mechanism

In the modified design the accumulator is removed from the system and the actuator is connected to the main hydraulic line through a sequential directional valve which allows the position of the slasher head to be controlled.



Figure 2 Hydraulic pump

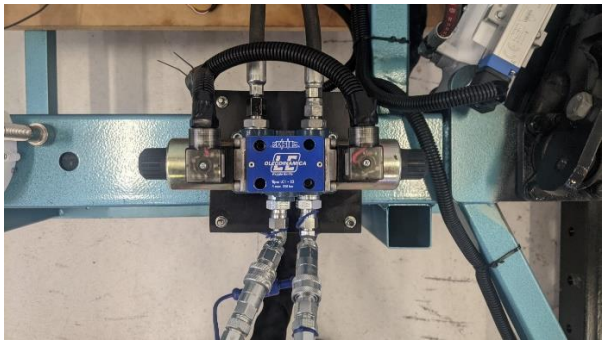


Figure 3 Hydraulic valves

Also, to increase the reliability of the system, a two-position failsafe switch is designed to be mounted to the slasher deck, which reverts the system to an open-loop impact slasher in the case of logic and electronic failure. With this addition, the system maintains the simplicity of existing systems, allowing the system to operate with its additional complexity while maintaining reliability.

Designing Sensing Mechanism

As stated in the introduction, to attain closed loop performance, reliable vine localisation is required. The harshness of a vineyard environment, including unreliable weather conditions, uneven terrain, variably sized vines, and inconsistent intra-row spacing, make vine localization an incredibly challenging task. The harsh conditions make implementation of common sensing options, such as vision or ultrasound impossible, thus limiting the sensing options to mechanical touch. The intrinsic characteristics of a soft touch sensor, such as being independent to environmental changes, having the capacity of mechanically detecting vines, etc, makes it extremely effective despite the harshness of a vineyard environment. In this section the process of design and development of a fit for purpose soft touch sensor for this project is explained. The proposed sensing mechanism is not only capable of reliably detect the position of the wine, but also, it can measure the size of each vine, which can be considered a measure of vine growth over each interval.

The proposed sensing mechanism is required to fulfill three main objectives. First, it must record the deflection of vines, then it needs to reset to its initial position after moving past each vine (both mechanically and electronically), and finally it needs to be able to freely move backwards past vines in case the system was to run in reverse. To satisfy these objectives a custom sensing mechanism has been designed for this system, shown in Figure 4.

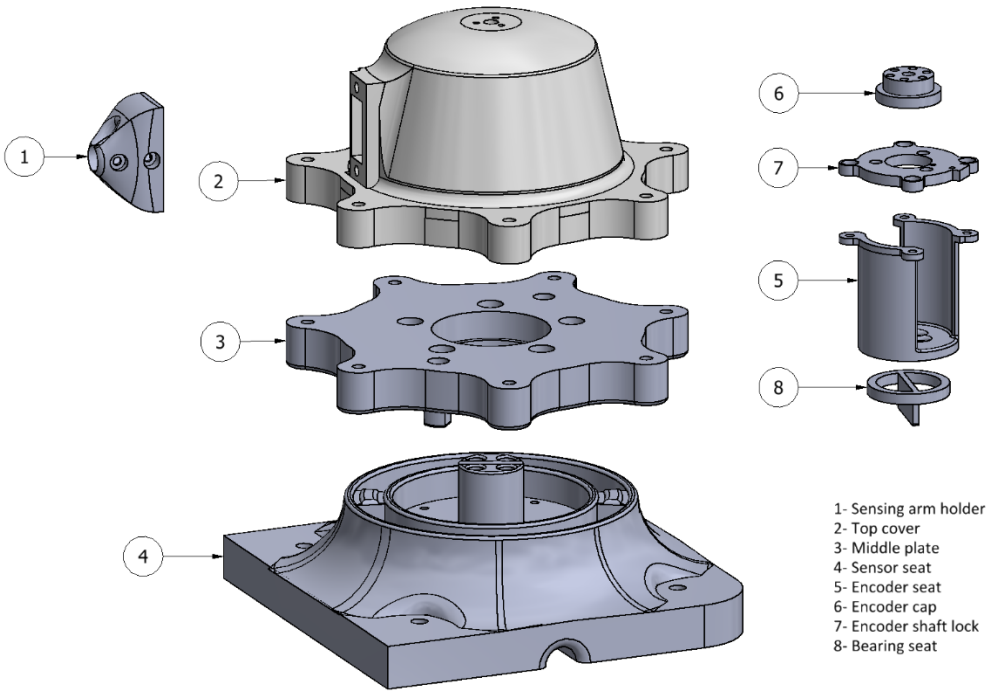


Figure 4 Exploded view of the sensing mechanism

The proposed sensing mechanism, consists of the sensor seat (which contains spiral spring seat, stator centre shaft and damping grove), middle plate (which is the location of the main bearing and is connected to spiral spring free end), encoder seat and cap (which contain the encoder and the limit switch), sensor top cover (including the mechanical limit reset, connected to the middle plate), sensing arm holder (holding the sensing arm pivoted to top cover), encoder shaft lock (screwed to the top cover connected

to the encoder shaft), and the main bearing internal seat (located in the middle of stator centre shaft). With this mechanism the vine sensing arm is just a simple aluminium rod connected to the sensor arm holder which pivots the sensor top cover. When the sensing arm encounters a vine, it causes the top cover, connected to the encoder shaft, to rotate. Given the top cover is screwed to the middle plate and middle plate it connected to the spiral spring, after passing the vine, the middle plate will position the top cover and the sensing arm back to their initial sensing position. The initial sensing position is defined mechanically via a damping grove structure which allows for 170-degree rotation, much more than required for any sized vine. The main bearing, located around the stator shaft, is fixed to the centre bearing seat with its outer ring connected to the middle plate, providing a low friction coupling between the top and base part of the mechanism. The base of the mechanism is fixed to the chassis. The sensing is done using an encoder angle sensor, shown in Figure 5, that fits into the encoder seat. This module is mounted to the base, on top of the stator shaft. The shaft of the encoder is fed through the top cover and is fixed to it via the encoder shaft lock, so that when the top cover rotates, the encoder shaft will rotate accordingly. Additionally, an electronic limit switch is mounted at this position so that when the mechanism rotates back to its known position, the switch is pressed, which can subsequently be used to electronically reset the system. In this mechanism grease is used in the damping grove to smoothen the actuation of the system. It should be mentioned the system has been design in a way that variable stiffness can be considered for the system respect to different operational conditions.



Figure 5 Rotary encoder and limit switch used

Figure 6 presents the first prototype of the proposed sensor assembly. Thanks to precise designing, this prototype fulfils all requirements for a sensing mechanism by recording the vine deflection through encoder pulses, automatically resetting (both mechanically and electronically), and only operating in a single direction due to how the sense rod is connected.

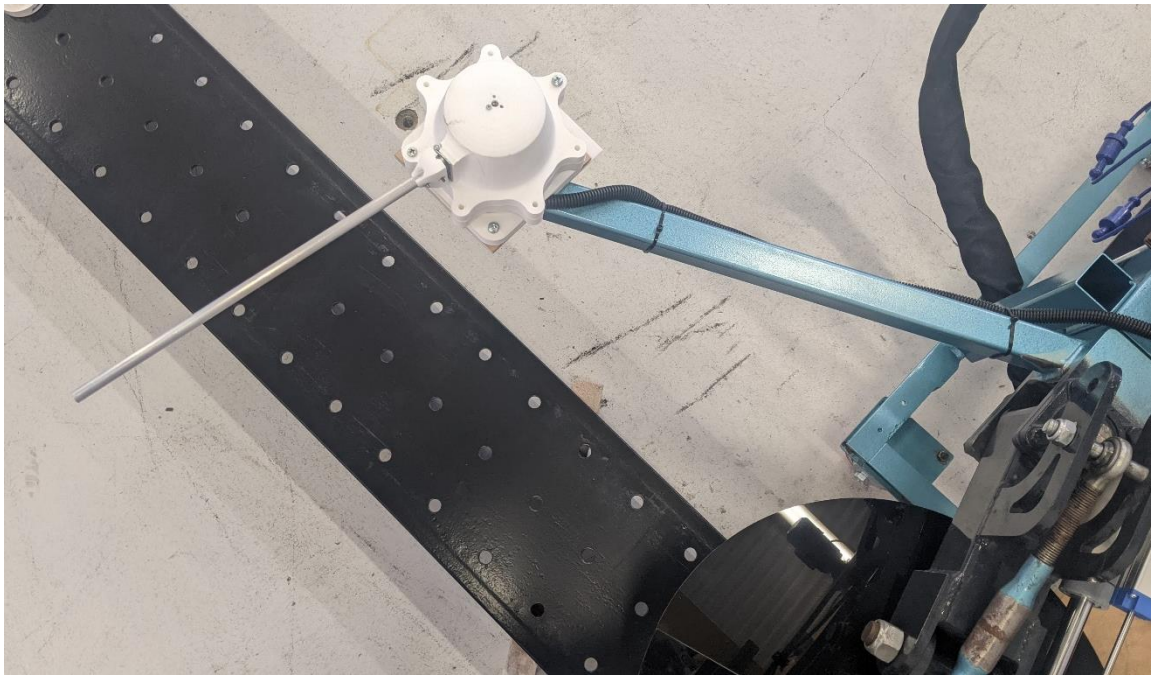


Figure 6 Sensing mechanism mounted to the system

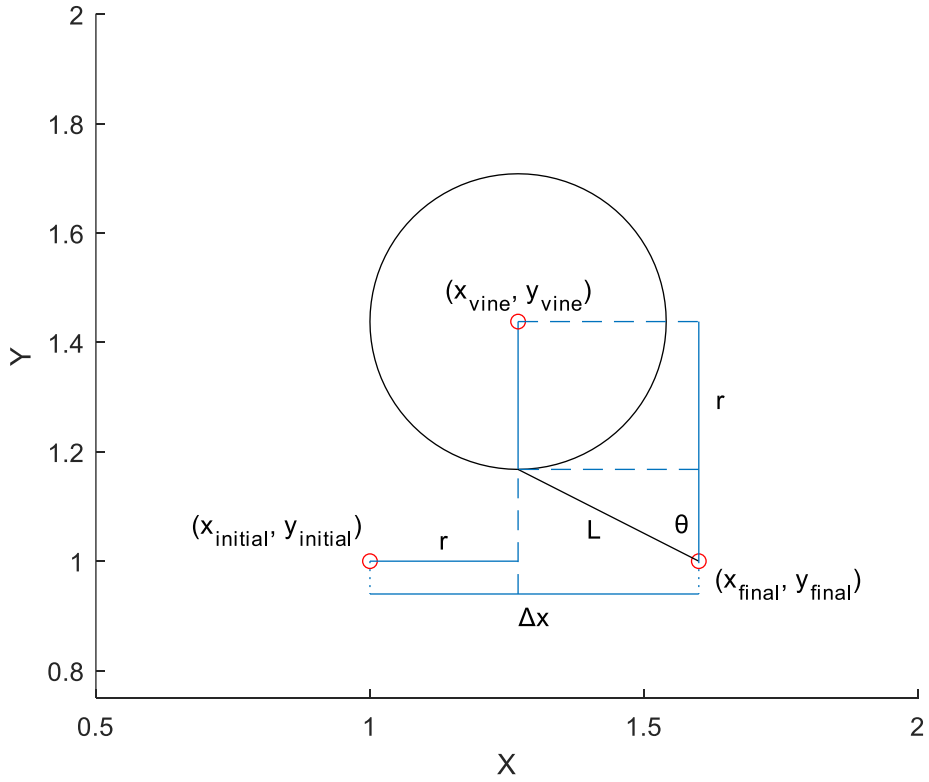


Figure 7 Final vine sense position with geometic identities overlayed

Figure 7 demonstrates the concept upon which the desired measures can be obtained from the sensor acquired data, initial touch timing, final touch timing and max deflection angle. As can be seen, the point at (x_{vine}, y_{vine}) represents the centre of the sensed vine with radius r. The length L is the length of the sense arm, the angle θ is the sense arm max deflection caused by the vine. The positions $(x_{initial}, y_{initial})$ and (x_{final}, y_{final}) are the position when the sense rod first touches the vine (the sense rod is typically running perpendicular to Δx), and the position when the sense rod is at its max deflection, respectively.

Using these lengths, the following equation can be formulated

$$r = \Delta x - L \cdot \sin(\theta) \tag{1}$$

And thus the x, y position of the vine can be found

$$x_{vine} = x_{initial} + r \tag{2}$$

$$y_{vine} = y_{final} + L \cdot \cos(\theta) + r \tag{3}$$

It should be mentioned that it is assumed all vines are of almost cylindrical shape, thus a single radius r could be a representative of the size of the vine. According to eq. (1), to obtain r, the max deflection and touch distance in the direction of movement is required. The position of the vine, also, is defined respective to the initial and final coordinate of the touch, which is detected via the limit switch embedded in the sensor assembly. Therefore, the size and position of the detected vine can be fully defined by the initial and final coordinate of the system, which can be identified with respect to the global coordinate.

System Localisation

As mentioned in the previous section, instantaneous localization of the mechanical touch is required to successfully execute the vine sizing and positioning. Precise localisation, also, is a necessity for other parts of the system such as path planning and actuation control, to be explained later. In this section the selection and implementation of the best possible localization mechanism, considering the existing vineyard challenges and limited on-board computational capacity is discussed.

Although there exist a variety of solutions for localization in different systems (including Ultrasonic, GPS, IMU, Image and LiDAR Localisation); just a few solutions seem suitable for vineyard applications due to the existing challenges mentioned earlier. For instance, Image Localisation, although precise, is not a viable option due to its significant computational costs and being easily affected by the harsh weather conditions. IMU and GPS Localisation may not be reliable enough due to the precise movement required, tractor vibration and weather conditions. Ultrasonic Localisation, also, requires vineyard alteration, which makes it not desirable for such applications. Among the remaining options, it seems LiDAR, being almost independent to the operational conditions and requiring minimum computational cost while delivering maximum reliability (due to its simplicity) [13, pp. 8-12], provides the best solution that serve the purpose of this project.

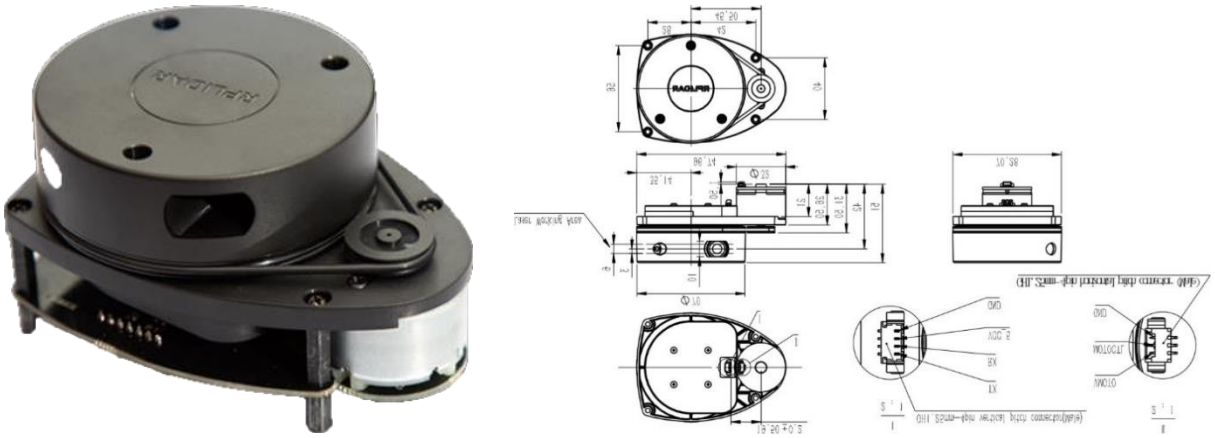


Figure 8 RPLidar A1 [14]

In this project the LiDAR model RPLidar A1, presented in Figure 8, is used. This model is an affordable option, commonly used for prototyping due to its well tested software libraries that make its implementation straight forward. In the current prototype, the Lidar is mounted vertically level with objects in the environment, as shown in Figure 9. The offset of the LiDAR base station from the base of

the slasher mechanism can be accounted for in software, allowing the system to operate normally regardless of where the LiDAR is mounted.



Figure 9 LiDAR mounted to the chassis

Hector SLAM is implemented as the software library for this project due to its minimum hardware requirements aside from the addition of LiDAR and its low computational cost [15]. Hector SLAM being a Simultaneous Localisation and Mapping algorithm creates an environmental map and simultaneously localises itself within it. The mapping, while not necessary for this system, could be used as a by-product of the localisation process to provide a complete mapping of the traversed environment for remote monitoring purposes.

Path Planning

With the system position now being localised, and the vine position and radius recorded, an optimal path planning is required for the system to avoid any detected vine. Real time path planning is implemented in this project over a more traditional path optimisation approach, as it is computationally lighter, while guaranteeing the control system will always have a position to reference, rather than needing to interpolate from each generated point to a corresponding position.

The proposed path planning algorithm for the smart slasher system is presented in Figure 10. As can be seen the planning is based around finding the position of the point at the centre of the slasher head, then for each x point as slasher head moves past the vine, generating a corresponding y point for the control system to use as a reference

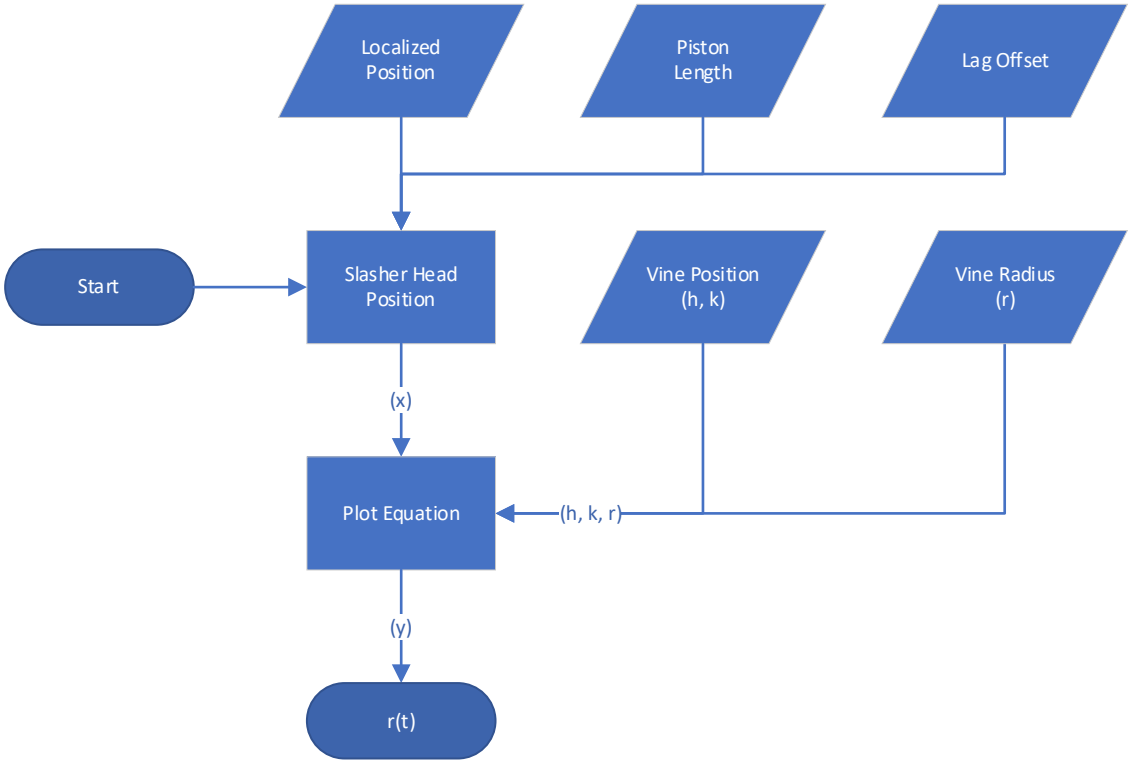


Figure 10 Algorithm diagram

The equation used to plot the slasher head path around the vine is derived from the following:

$$(x-h)^2+(y-k)^2=r^2 \tag{4}$$

The only variables of this equation are x and y. Since y is the reference value to be found, one can rearrange eq. 4 for it, which leaves x as the only variable – the centre point of the slasher head.

$$y=k-\sqrt{(r+x-h)(r-x+h)} \tag{5}$$

Where y is the reference value to be found, h corresponds to the x position of the vine, k corresponds to the y position of the vine, and r corresponds to the radius of the vine. Since these values have already been found and recorded for the corresponding vine, by receiving x from the localization system, a real time path can be depicted to be used for moving the centre of the slasher head while slasher deck moves past the vine.

To check the practicality of the proposed simple algorithm, a vine position, (h,k,r), of $(0,2,1)$ is considered.

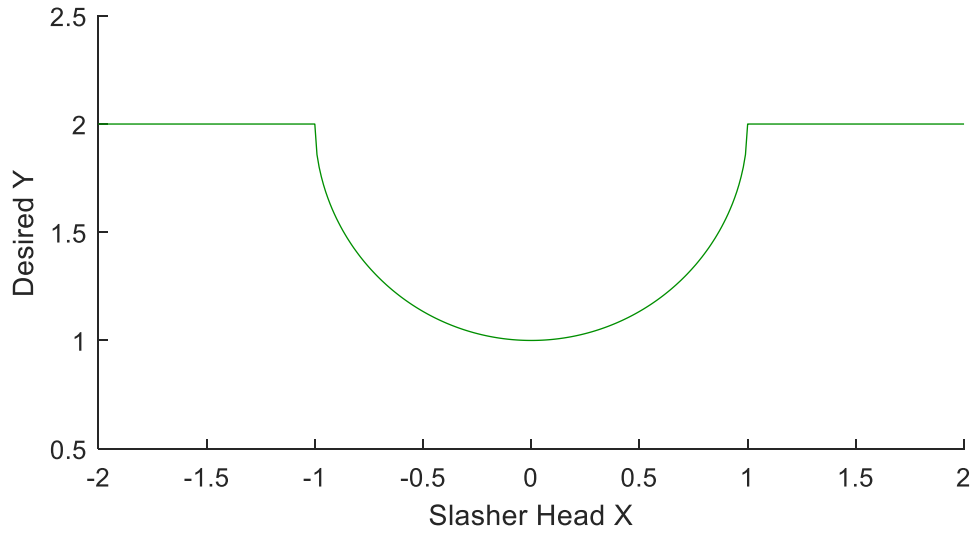


Figure 11 Plot of y against x at $(0,2,1)$

As seen in Figure 11, the vine is plotted as a semi-circle with the centre point (h,k), and the radius r. As the x position of the slasher head starts moving towards the vine, it will first start in line with the centre of the vine radius, in this case, at $y=2$. Then, as it moves closer to the centre of the vine, it will begin to move around it in a shape of a semi-circle, the centre of the slasher head will stay a fixed distance away from the centre of the vine, in this case $r=1$. Once the slasher head has moved past the vine completely, it will then stay in line with the vine centre, $y=2$, until another vine is sensed. The value of r in the actual system will be defined from a combination of the slasher head radius, vine radius, and safety factor, as shown in Figure 12.

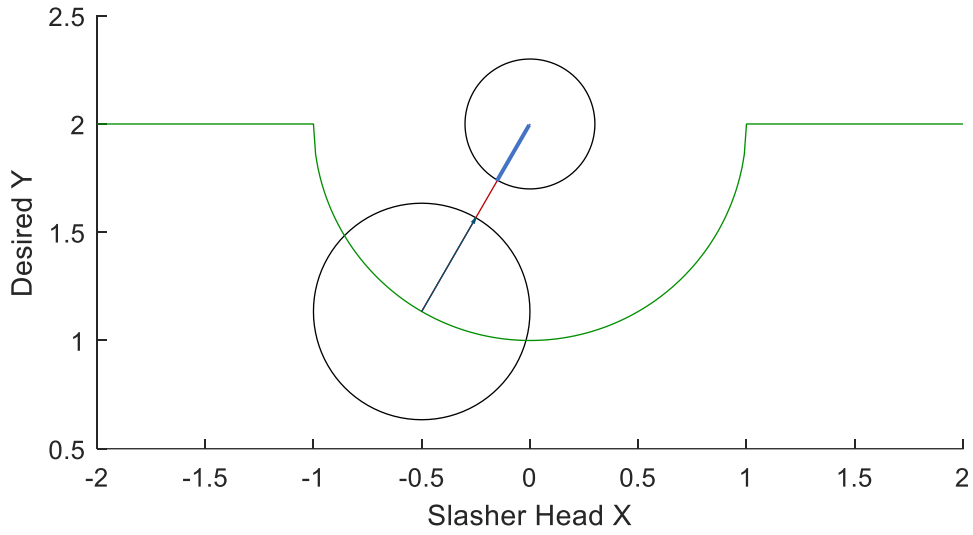


Figure 12 Plot of y against x at $(0, 2, 1)$ with vine radius, slasher head radius, and safety factor included

For this case, the vine radius and the slasher head radius are considered to be $0.3m$ (the light blue line) and $0.5m$ (the dark blue line), and the safety factor is $0.2m$ (the red line). The resulting radius is the combination of the three values (shown in green). Accordingly, if the control system can hold the centre position of the slasher deck on the green line, a safe, contact free slashing would be achieved by the system.

Control System

With a suitable path plan generated, the control system directly operates the slasher in accordance with the planned path. There exist varieties of sophisticated control systems that can easily serve the purpose; however, considering the degree of freedom of in the actuation of the system under investigation, as well as the limited computational capacity of the onboard system, implementation of such state-of-the-art control systems would not be justifiable for such an application. On top, given a high level of simplicity is desired by the end user, using a complex control system would turn the entire system into a black box, not a user-friendly system for the end user. Considering this, a simple three-state control system with hysteresis is proposed for this project. In the proposed system the controller sets the actuation mechanism to one of three possible states: retracting, extending, or off. The proposed control algorithm is presented in Figure 10. As can be seen, the control system works by measuring the actual length of the slasher arm using a linear potentiometer and compares it to the reference length calculated by the path plan. The difference between these values is considered as the error signal. This makes the actuation system relatively simple; If the error is negative, the system should retract, if the error is positive, the system should extend. Finally, if the error is equal to 0 ± 0.04 (min value), the system consider itself close enough to the desired value. It should be mentioned in such systems, due to its mechanical limitations, the controller typically lags behind the planned path. In the proposed algorithm this behaviour is compensated by a respective lag offset.

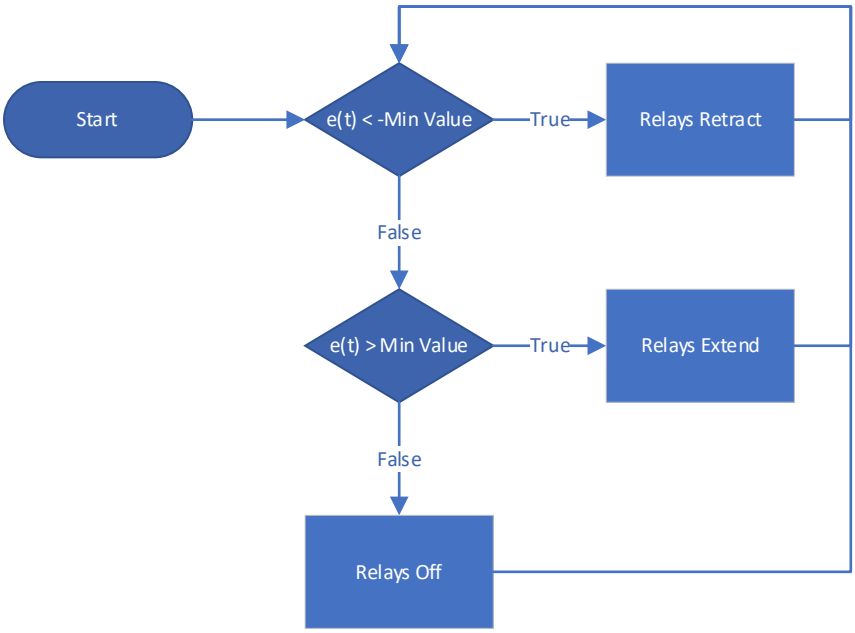


Figure 13 Control System diagram

The error signal, $e(t)$, in the system can be defined by $r(t) - y(t)$, where $r(t)$ is the reference value generated by the path plan.

Figure 14 shows a more detailed view of the slasher mechanism with respective lengths and angles used in the control algorithm coding. As can be seen, since all lengths in the slasher mechanism are constant

aside from the piston (denoted 'S'), the $y(t)$ position of the slasher head can be directly related to the change in the length of S.

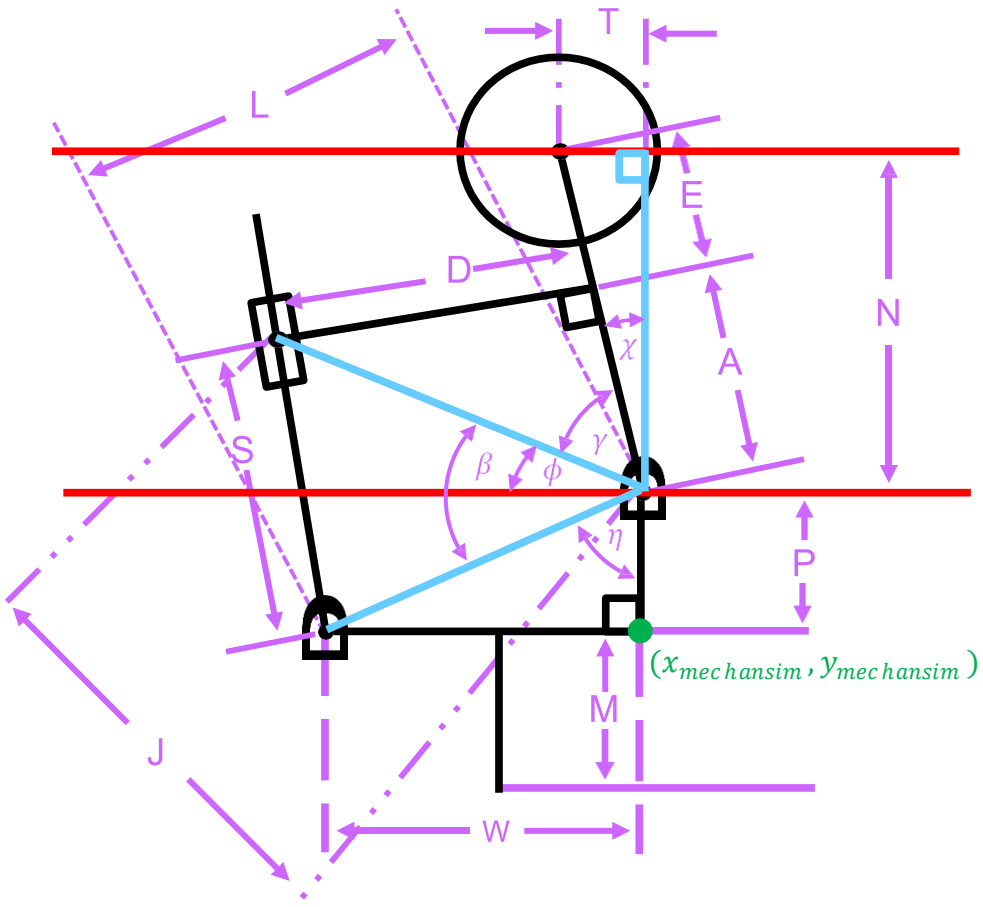


Figure 14 Kinematic diagram of the slasher mechanism

From Figure 14, the x and y positions of the centre of the slasher head are given with the following equations

$$x = x_{mechanism} - T \tag{6}$$

$$y = y_{mechanism} + P + N \tag{7}$$

Where $x_{mechanism}$ and $y_{mechanism}$ are the corresponding x, y points at the bottom right corner of M and W found using LiDAR localisation.

Additionally, the length P is constant and the lengths N and T are given by

$$N = (A + E) \cdot \cos(\chi) \tag{8}$$

$$T = (A + E) \cdot \sin(\chi) \tag{9}$$

Where A and E is constant and χ is given by

$$\chi = \pi - \eta - \beta - \gamma \tag{10}$$

Where all angles are constant except β, which relates directly to S by the following equation

$$\beta = \arccos\left(\frac{-S^2 + J^2 + L^2}{2JL}\right) \tag{11}$$

The values of J and L are derived constants, and the length of S can be measured using the linear potentiometer. Thus, the y position of the slasher head can be determined in relation to the change in the length S. By comparing $y(t)$ with the y component of the generated path (at its instantaneous x position captured via LiDAR) the control system produces a respective actuation signal, forming a simple closed-loop operating system. With the system operating accordingly, the slasher deck can avoid the detected vine without any direct contact. Also, given there is no speed dependency for this actuation relative to vine, the actuation speed is only limited by the hydraulic unit power and the software speed which are far beyond the expected requirement. This also, adds the capability of speed modulation slashing, which removes the requirement of a constant operating speed.

System Integration

Each of the previously discussed elements have been brought together to form a complete system. This section will explain the process of how each of these elements have been combined and the effectiveness of the complete system.

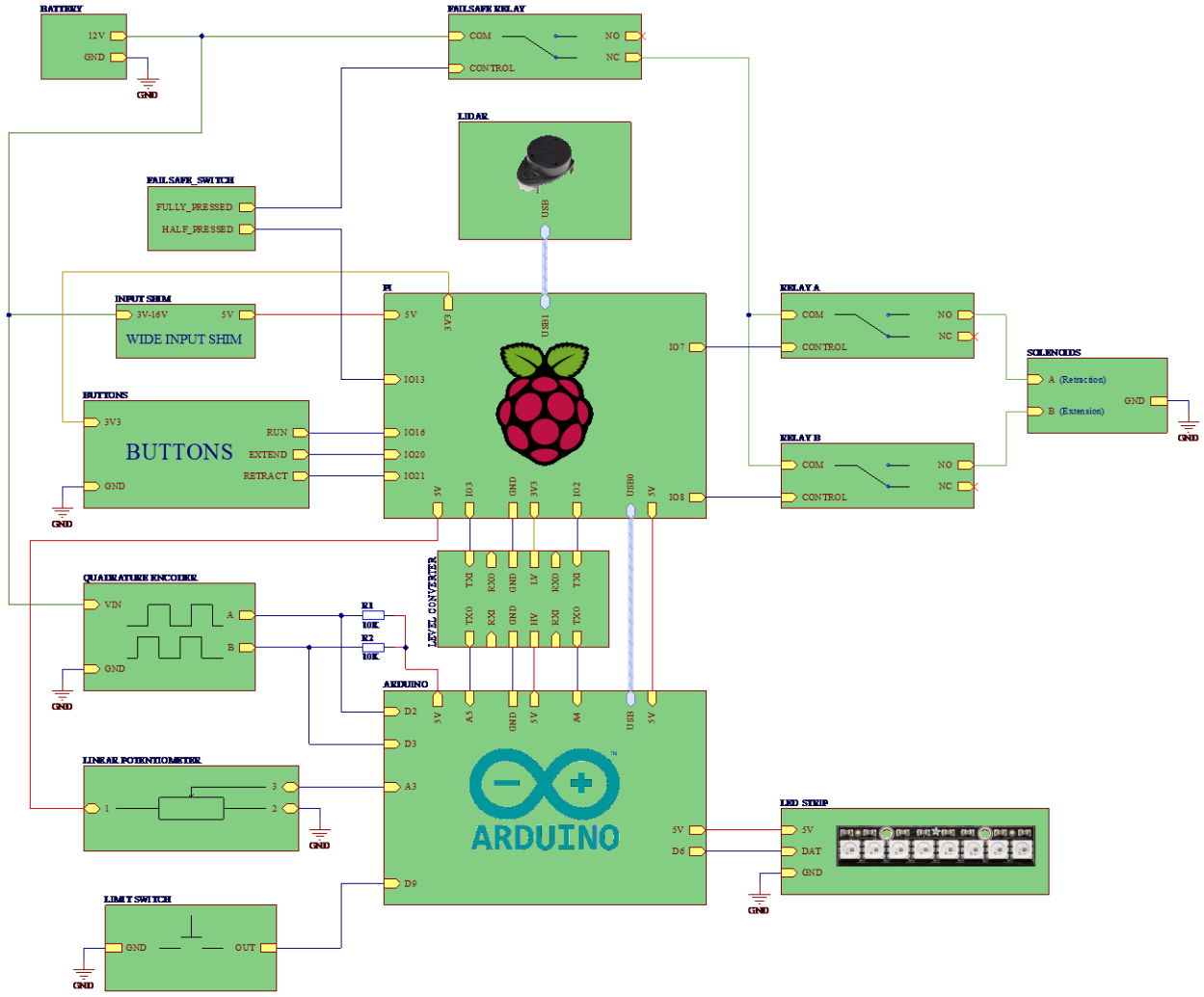


Figure 15 System block overview

The system block overview, seen in Figure 15, shows how each sub-system "block" connects to the system. When the system runs, the sensing mechanism localises the position of a given vine. The vine position is used to generate a real-time path around the vine, which updates as the system continues to move. The planned path is used by the control system, which generates a suitable control signal. The control signal moves the slasher head by either extending or retracting the hydraulic ram of the slasher, causing the slasher head to move proportionally. The length of the hydraulic ram is used by the control system and path planning to form a closed-loop system.

The system has been integrated using ROS. ROS is an open-source, meta-operating system that is commonly used in robotics [16]. In the proposed system, sensing, path planning, and control are all implemented as separate ROS nodes, along with additional nodes for manually controlling the slasher head position using onboard buttons and a remote joystick setup, as well as a node running on an independent microcontroller that reads sensor data and updates the system status LED. An overview of the system nodes, along with corresponding topics (with labels prepended by '/') can be seen in Figure 16.

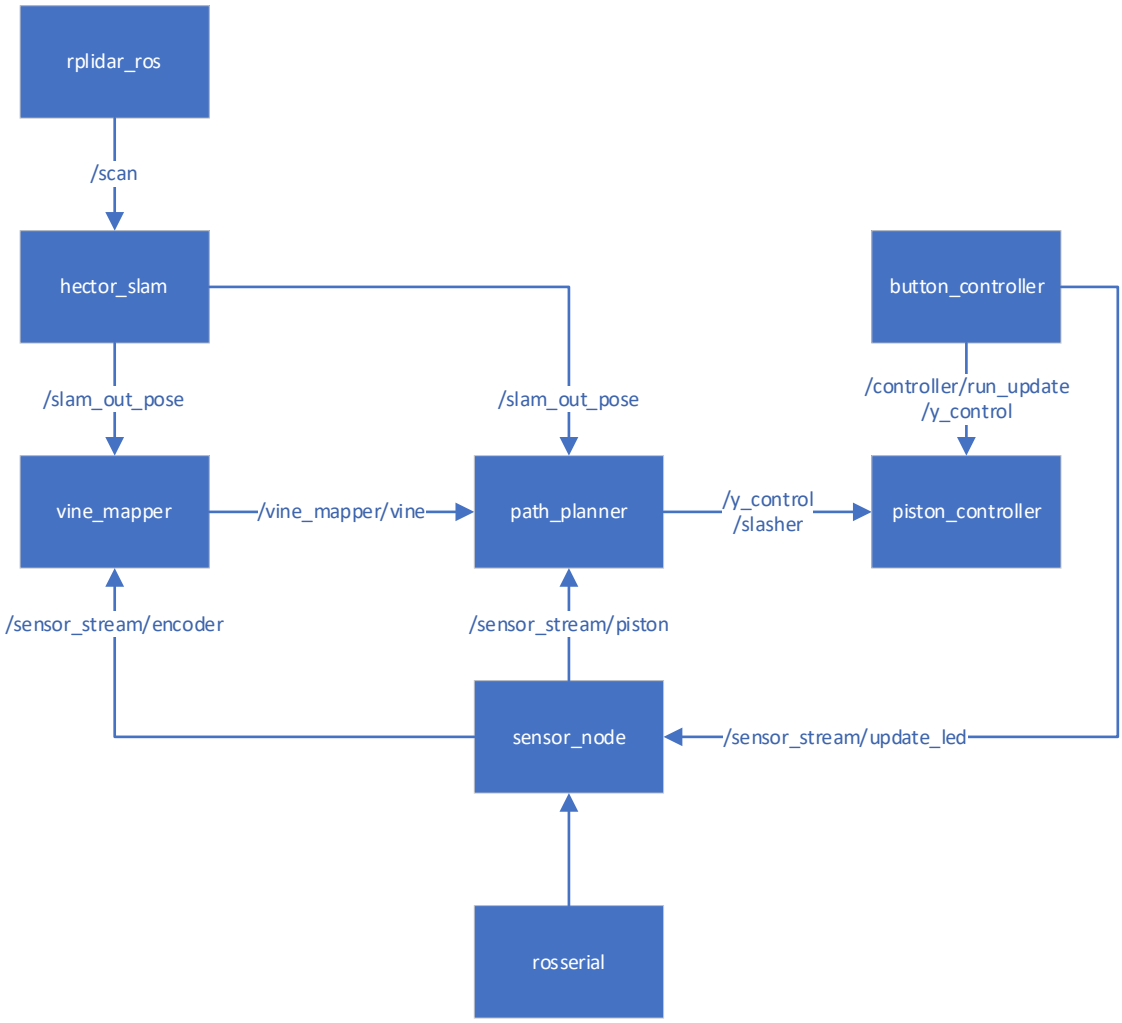


Figure 16 ROS node communication diagram with topic names

Networking is an additional benefit of ROS. With several computers operating on the same network, ROS is able to operate over the network, utilising the computational power of less portable, more powerful machines. Running the system over a network allows for remote system monitoring and control, as long as the network connection is consistent. This allows the system to be tuned remotely, without the need to halt the system, as well as allowing real-time data analysis.

In this project RViz is used for remote monitoring and data acquisition. RViz is a visualization tool built into ROS. The integrated system uses a node that takes data from existing topics and generates corresponding visualizations from them. The diagram of this can be seen in Figure 17.

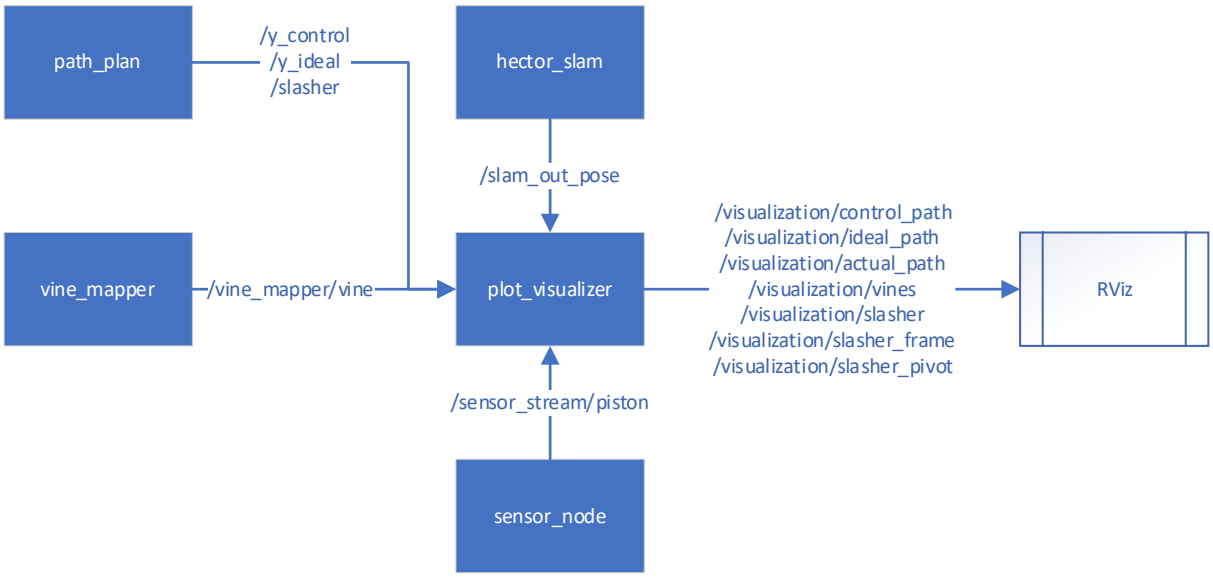


Figure 17 Visualization diagram

The benefit of this implementation is that it requires no modification of the original nodes, and the visualizer node can be disable if RViz is not in use. Additionally, with the use of remote networking, the visualizer node can be run on an external computer, creating a completely independent system that adds no additional processing overhead to the main system.

System Performance

To quantify the system performance, it has been run in a controlled environment. The test environment, shown in Figure 18, consists of three PVC pipes. The radii of each of these pipes, from left to right, are 55mm, 22.5mm, and 40mm and the spacing between them are 1.8m and 0.9m, respectively.

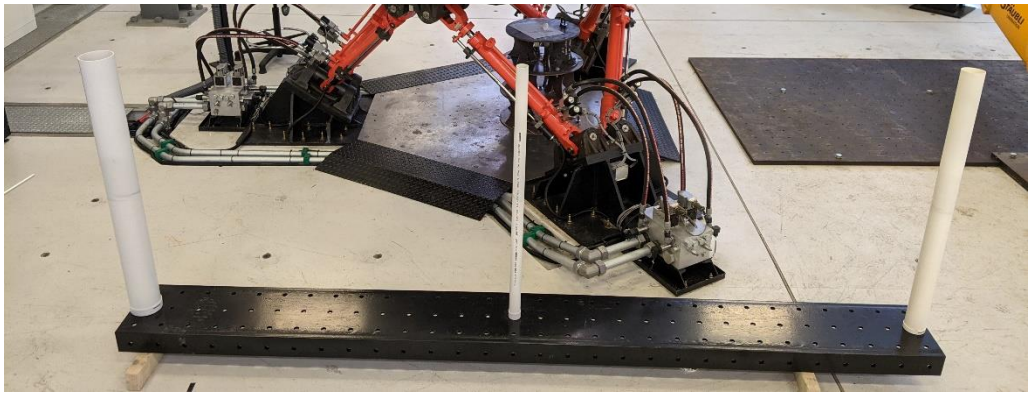


Figure 18 Test enviroment

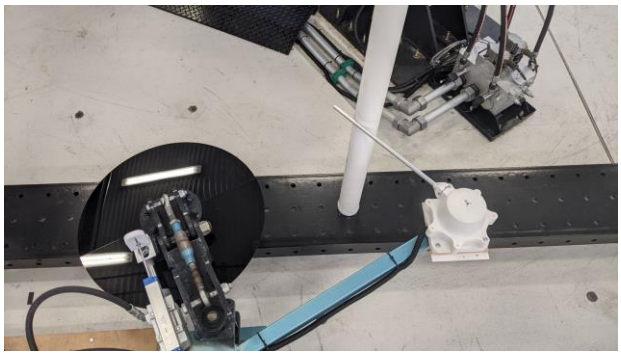


Figure 19 System sensing vine

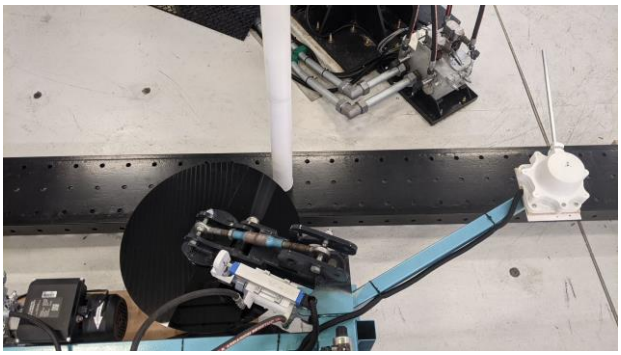


Figure 20 System avoiding vine

The system performance has been examined at three different speed 1k/h, 1.5 k/h and 2 k/h over three different vine replicas. These speeds have been limited by the hydraulic power of the set up (with 1/10 of the power of a regular tractor hydraulic unit in the field) due to safety regulations. In the visualisations of the three runs over the three vines, presented in Figure 21, the pink cylinders represent the sensed vines, the pink lines represent the planned path, the blue lines represent the control path (with an offset of the planned path to compensate for control system lag), the green lines represent the actual slasher head path, and the green figure represents the current slasher head position (including slasher head radius). As can be seen, the proposed system successfully accomplished the mission on all three different runs. The promising performance reflect the reliability and repeatability of the proposed setting. Also, it is demonstrated that the performance of the system is speed independent; and considering the power of the hydraulic unit in the field, the actual performance speed can grow up to minimum 10 times the recorded speed.

Run A

Run B

Run C

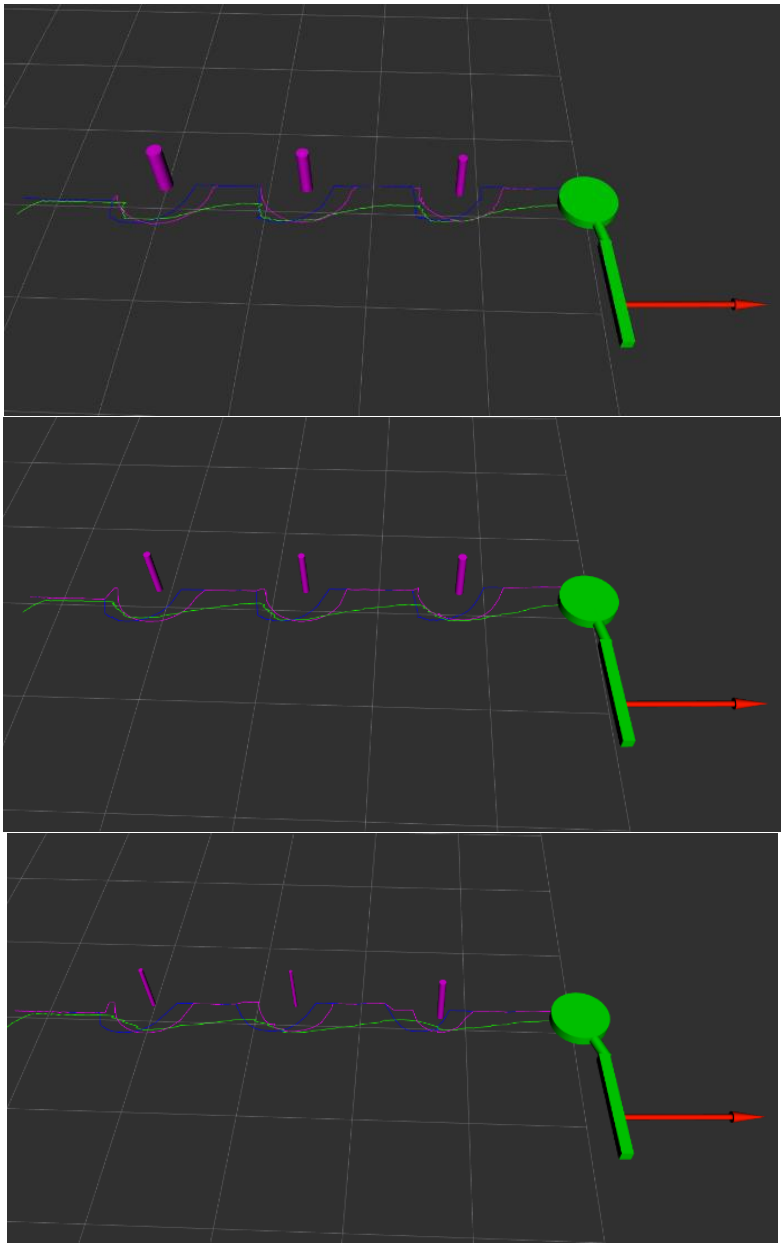


Figure 21 System performance visualization: Run A 1k/h, Run B 1.5k/h, Run C 2k/h

The presented performance clearly demonstrates the effectiveness of the proposed control algorithm. In all the three runs the executed simple control system succeeded to keep the slasher deck (Green line) as close as possible to the planed path (Pink line). It may be noted that the slasher head path does not exactly follow the planned path between the vines. This is because the slasher head maximum position is less than the planned path thus even though fully extend is mechanically limited and cannot match the planned path.

The runs also show that the slasher head path becomes straighter the faster the system runs. As stated earlier, this is due to the limited hydraulic power available in this test setup, which is mandated by lab safety regulations.

Regarding the sensing mechanism, the performance indicates the sensing system, although made from plastic component, is fully capable of detecting the vine correct positions across each run. However, the vine sizing appears to shrink as the system speed increases. This can be due to movement of the PVC pipes during the operations.

Overall, it is vivid that the developed semi-automated slasher has successfully fulfilled all the requirement and objectives of the project. For the current prototype, on top, the digital twin of the system, also, has been executed, presented in Figure 22. The executed digital twin enable real-time monitoring and control of the system which provides the capability of using current system in a fully autonomous operation. In the proposed design for very low additional cost, an observer operator can take control of the system and remotely manoeuvre through difficult situations, while receiving real-time feedback from the system. The implementation of this system requires a low-performance computer (running opensource software) and any kind of control interface, such as a keyboard or joystick. This is a simple, cost-effective way to control the system remotely, and it can be used solely for monitoring and mapping in situations where manual control is not appropriate.

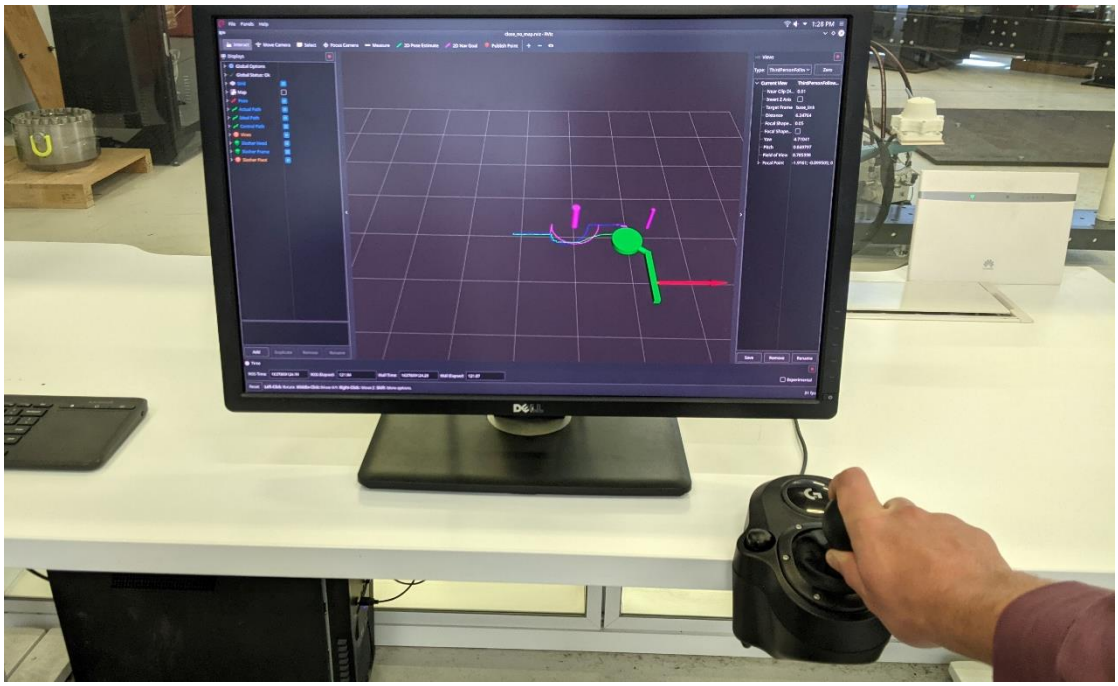


Figure 22 Using remote operation to control the system while monitoring changes

Conclusion

This project provides a semi-automated, soft touch, under-vine slasher that can successfully avoid vines. The proposed system fulfils the market requirement of an easy to operate, variable speed, effective, and affordable under-vine slasher. Along with the original requirements, the system also provides a way to remotely monitor and control the prototype slasher in real-time, this could be used to track vine growth over a period, or manually actuate other attachments. The benefits that this system could bring to the sector are a reduced cost of operation due to not requiring a specialist driver, more efficient crop management due to more flexible operating speeds, and reduced crop damage due to less aggressive vine contact. Along with all of this, the system remains cost-effective, making it applicable in many areas of this sector.

Future Work and Recommendations

This project demonstrated the proof-of-concept of a simple under-vine slasher. For future work, the system complexity can be increased with additional hardware improvements to undertake more complex tsks such as pruning. In the current system the following options can be upgraded for a better performance: The sensing can be made more accurate by using a higher quality LiDAR module; The path planning can be improved using a system with higher computational capacity; The actuation can be improved by using variable flow control. Etc. Each of these improvements would allow the system to operate at a higher capacity. In doing so, plus the implementation of the learnt lessons during this project, the team would be ready to move to automated vineyard precise pruning system, a highly desired development by the end-users.

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Appendix1: Communication

During the project the outcomes have been communicated through series of progress presentations ended up with a final presentation. The outcomes of this project, also, have been published in the form of three Honours theses and have been documented at Flinders library:

- Design of An Automated Vineyard Slasher
- The Development of a Physics- Based Digital Twin of a Flow Control System to Be Used for Precise Positioning and Control of Hydraulic Ram
- Development of a Hydro Control System for a Remote Robotic Application

The provided report, after minor changes, also will be published in relevant journal.

We believe by being introduced to potential investors the project, which is currently in the stage of prototyping, would have the chance to find its pathway to the market.

Appendix 2: Staff

The staffs involved in this project include:

1- Amir Zanj as the CI and management
2- John Harnett as industry collaborator
3- Warren Brichmore as the end user industry advisor
4- Paul Smith on WA panel

And the following research assistances:

5- Alex Ostich
6- Daniel Bigrimana
7- Hayden Skinner
8- Gabriel McGrane
9- Coober Wolfden

Appendix 5: Final Presentation Slides



AVMS- final presentation.pptx