An Autonomous Platform for Use in Kiwifruit Orchards

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Abstract

This will be written last. Other uses may be mechanical weed removal, targeted spraying, and crop scouting.

Keywords:

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1. Introduction

Short-term labor requirements within the New Zealand kiwifruit industry peak twice a year corresponding with pollination and harvesting cycles. The majority of employment in this industry during these peaks is filled by seasonal or casual workers (Timmins, 2009). As kiwifruit is New Zealand's largest horticultural export by value (Statistics New Zealand, 2015), automation in kiwifruit harvesting and pollination should ease growth in this industry. Additionally, the New Zealand government aims to double exports from its primary industries between 2012 and 2025 and is actively investing in programmes to achieve this (Ministry for Primary Industries, 2015).

Previous work on automated harvesting of kiwifruit has been demonstrated (Scarfe, 2012; Scarfe et al., 2009). That work presents a harvesting platform with the capability of in-orchard kiwifruit harvesting from pergola type orchards. The robotic platform presented in this paper is a second generation unit based on that previous, more integrated, design of kiwifruit harvester. Modularity of the platform has been increased to so as to be able to accommodate other modules, such as those for harvesting and pollination.

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This work discusses only the base platform, where details of the harvesting and pollination modules are published separately (Williams et al., 2017; Seabright et al., 2017).

Automation in harvesting and pollinating kiwifruit demands the use of real-time computer control, state-of-the-art manipulators, and convolutional neural networks. In their current state of development these systems are bulky and have specific geometric requirements dictated by the environment they operate in, namely pergola style orchards. They share common requirements in that they both require transport to and from orchards, electrical power, and air pressure, but differ in they way they move the orchard. Whilst pollinating, the platform must move at a well-known velocity with minimum changes in angle, whereas harvesting repeatedly starts and stops, advancing set distance between cycles. The duration of any given harvesting cycle is determined by the number of fruit to be harvested during that particular cycle. Therefore, as the harvester is designed to be autonomous, there must be communication between the harvester and platform to trigger forward movement after each harvest cycle.

It has been stated that "since the robot development already includes a high complexity, the application itself should be of comparably low complexity" (Ruckelshausen et al., 2009). By separating development of the base platform from the task-specific modules, risk of over-complexity is reduced by way of isolation. The platform presented here simply needs to transport the separately developed modules through kiwifruit orchards autonomously.

Many autonomous vehicles for use in the agricultural industry have previously been reported, many of those being conversions of existing vehicles into a self-driving form. While this can reduce the initial cost for development of self driving systems, the cost of deploying such units may make them commercially unfeasible. In this work we present an agricultural vehicle designed specifically for use in kiwifruit orchards to transport modularised pollinating and harvesting units.

2. Review

The introduction of computers and digital camera technology during the 1980s sparked research into creating autonomous vehicles for agricultural use Li et al. (2009). When publishing details of an autonomous vehicle in 1999, Tillett et al. cites difficulties dealing with variability in lighting and the environment as the reason no commercial ready vehicles were available at the time. His vehicle used wheel encoders, a compass, and accelerometers for odometry information, and featured a camera based row guidance system. It was capable of spraying individual plants whilst autonomously driving at $2.5\,\mathrm{km\,h^{-1}}$.

Later, in 2002, Pedersen et al. (2002) presented an Ackermann based autonomous robot designed for weed mapping. It had a top speed of $6\,\mathrm{km\,h^{-1}}$ and used GPS to determine the absolute position of the vehicle at semi-regular intervals. Between those updates, odometry estimates based on a gyro and compass were used. Their vehicle was designed to follow pre-defined paths through row-crops, but the authors found that this was impractical without a dedicated row guidance sensor.

These reports suggest that neither perception based row guidance nor absolute positioning, such as by GPS, are suitable on their own for agricultural vehicle guidance.

Bak & Jakobsen (2004) presented a relatively advanced robotic platform based on a four wheel steering geometry. The authors noted that the control strategy for the four independently controlled wheels was non-trivial. Like the platform presented earlier by Pederson et al., it combined a compass, gyroscope and GPS for odommetry. However, it also featured encoder feedback, a row detection sensor and a GPS unit utilising Real Time Kinematic (RTK) corrections from a base station. RTK-GPS is capable of providing positioning with accuracies of around 2 cm. Their robot utilised a Controller Area Network (CAN) bus for some aspects of system communication.

In 2008, Klose et al. publish details of 'Weedy', a autonomous weed control robot for field use. It used a simplistic four wheel steering geometry. There are few details on the sensor selection apart from mention of the use of cameras and 'acoustic distance sensors'. Presumably the selection of drive geometry on this robot is a cost/complexity optimisation. It too makes use of a CAN bus for communication between on-board modules.

The following year, many the same authors appearing on the 'Weedy' paper published details an autonomous robotic platform with four wheel steering named BoniRob (Ruckelshausen et al., 2009). BoniRob had the ability raise and lower itself and alter its wheel placement by actuating the arms to which the motors are attached to. Similar to the unit presented by Bak et al. it features a gyroscope and RTK-GPS for localisation. It introduces the use of both 2D and 3D laser-scanning (or lidar) for perception and row detection. A CAN bus is used to control the low level systems (such as the drive control) and ethernet connections for higher level communication. The authors created a simulated model of the platform using Gazebo in which they could test the many-degrees-of-freedom drive system.

Of particular relevance is the work of Scarfe et al. on an autonomous kiwifruit picking robot (Scarfe et al., 2009; Scarfe, 2012). That work involved the creation of a hydraulically driven platform with Ackermann steering to which four fruit harvesting arms were integrated. For navigation it used lidar, camera based machine vision, GPS, and a compass. The development of that robot forms much of the foundation for the work presented here.

Common among these vehicles is the use of sensor fusion, whereby data from multiple sensors is merged and filtered. This provides a way to combine the advantages of multiple sensor types, and the benefit of redundancy from multiple sensors, into a single computation space. With regards to the use of RTK-GPS of perception based guidance systems, Slaughter et al. points out the trade-off of requiring an "unobstructed "view" of the sky from all parts of the field" (Slaughter et al., 2008). Additionally, multi-path signal propagation caused by nearby foliage or the geometry of the land itself presents its own mode of failure (Durrant-Whyte, 2005). This requirements can not be satisfied under the canopy of a kiwifruit orchard which are then surrounded by tall wind-breaking hedges. A separate feasibility analysis highlighted the use of RTK-GPS systems as a significant cost in yearly subscriptions alone (Pedersen et al., 2006). Torii suggests a combination of both RTK-GPS and machine vision systems to be the most promising system going forward based on reductions in costs and increases in performance of these systems Torii (2000).

Blackmore et al. (2007) envisaged significant reductions in production costs by re-purposing parts already in use in the agricultural and automotive industry. While not a physical component, the CAN is one such technology borrowed from the automotive industry aiding developmental of low-level communications. Many of the platforms reviewed, especially the more recent ones, made use of this protocol for real-time communication. Platforms designed for open field crops appear to favor four-wheel steering over the more traditional Ackermann geometry. The use of simulation tools allowed the creators of BoniRob to develop and test their mobility system separate of the physical hardware.

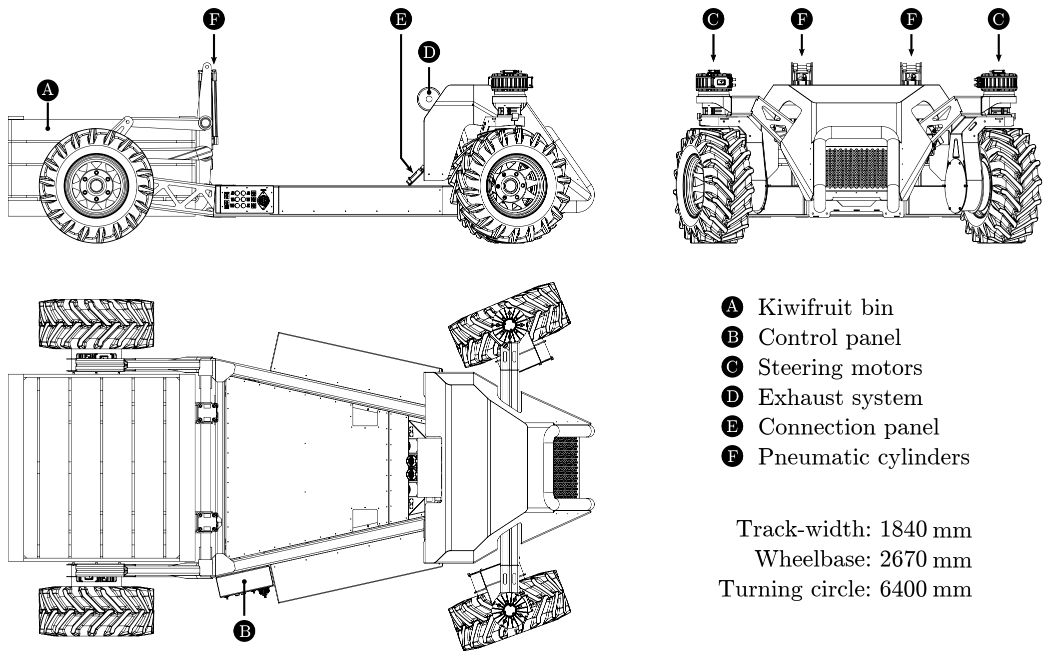

Figure 1: Profile drawings of the robotic platform with kiwifruit bin.

3. Mechanical design

Canopy heights of kiwifruit orchards range between 1300 mm and 1700 mm. Modules on the platform need additional clearance from the canopy in addition the height of the module itself. To maximise space available to the modules it carries, the platform must be low-slung where these modules attach. Figure 2 shows the design of the platform, with its module area is visible between markers ‘F’ and ‘E’ in the side view (top left).

Steering geometry is Ackermann based with independent motors on the front wheels for actuation. The ability to actuate the angles individually simplifies the mechanical geometry needed to coordinate the steering wheels, especially at the extreme angles. Each steering wheel has the freedom to rotate 340°, which gives the platform the ability to pivot about the centre of its rear wheels. This sets the turning circle to be twice the distance from the centre of the rear wheels to the front of the vehicle. Implementing four wheel steering would allow the centre of rotation to move to the centre of the vehicle, decreasing the turning circle to the total length of the vehicle. As the headlands of kiwifruit orchards are sized for tractors to turn between rows, Ackermann based steering is sufficient. The implementation of Ackermann geometry simplifies the overall design and increases the usable area at the rear of the vehicle; allowing a full-size kiwifruit bin and lifting mechanism to occupy this space. Not only does the Ackermann geometry offer a reduction in mechanical complexity, but also removes the need to develop the "non-trivial" control strategies. A differential drive, or skid steer, system was expected to cause ground damage to a level considered unacceptable to orchard owners.

The platform has no suspension, other than its tries, and features a front pivoting axle to maintain three points of contact with the ground.

Pivoting front axle used to maintain three points of contact at all times; no suspension. Limited to $10\,\mathrm{km\,h^{-1}}$ by the choice of motor and gearboxes on the drive-system. Operational speed of $5\,\mathrm{km\,h^{-1}}$. Ackermann steering geometry with the ability to pivot about the centre of the rear wheels. Four wheel steering, such as presented by Bak & Hans (Bak & Jakobsen, 2004), was not deemed necessary as the headlands of kiwifruit orchards provide adequate turning areas. Additionally, control strategies for a platform having only two steerable wheels is simpler.

(Åstrand & Baerveldt, 2002) have used an ackermann steering system actuated by a single DC servo motor for their robotic beet-crop weeding platform. They have only two driving wheels placed at the rear of the system.

4. Hardware

GPS has proven to be unreliable when used under the dense canopy of a kiwifruit orchard. (Pedersen et al., 2006) shows the economics of using an GPS-RTK system, as seen in other agricultural systems (Bak & Jakobsen, 2004; Ruckelshausen et al., 2009)[Nagasaka et al from (Torii, 2000)], has considerable ongoing costs in the form of yearly fees, although the cost of these units is rapidly decreasing (Torii, 2000). Forward and upwards facing LiDAR have been used for navigation and detection of the row and canopy.

5. Safety

Relay modules connected to the main computer via the system's CAN bus give a means of shutting down subsystems. These relays monitor the platform's CAN bus to ensure that synchronisation messages are being sent

Figure 2: Photo of the platform during development showing battery housings and system internals. Battery compartments are visible along the sides of the chassis.

out in a timely manner. In the event that the synchonisation messages begin to vary in frequency, or stop, the relays cut power to the subsystems. Both front drive motors are fitted with electromechanical brakes which engage when the power is cut. A wireless safety-rated controller, designed for use with cranes, has been adapted for use with driving robot platform. The controller provides the operator with a way of entering the platform into autonomous mode, manual control, triggering an emergency stop, or enabling/disabling auxiliary systems.

6. Software architecture

The control software is comprised of individual nodes, writen in either C++ or Python, linked together using Robot Operating System (ROS) for interprocess communication. The system runs on Ubuntu Server 16.04 on an Intel NUC, a compact x86 based PC. A model of the robot platform has been depeloped for use with Gazebo simulation software. Such a model provides a way to test steering and movement strategies before deploying them on the hardware.

7. Sensor selection

[Jamie's section]

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