

# 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 fit other modules, such as those for harvesting or pollination. This

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work discusses only the base platform, where details of the harvesting and pollination modules are published separately.

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. As part of a wider kiwifruit automation project, of which this research falls into, two modules have been developed for the tasks of artificial pollination and kiwifruit harvesting. These modules share common requirements in that they both require transport to and from orchards, electrical power, and air pressure, but differ in the way they move the orchard. The pollination module is designed to move at a well-known velocity with minimum changes in angle, whereas the harvesting module 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 the base platform to make efficient use of time. That communication can be as simple as a command analogous to ‘harvesting completed, move forward’, but highlights the need for an autonomous platform to guide the modules.

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 [Mark chuck some references here]. 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. The weight and size of these units requires a vehicle that is robust, computer controllable, low-slung, and is capable of performing turns between rows.

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 the base platform from the more specialised task-specific modules, risk of over-complexity is somewhat reduced. The platform presented here has one simple application in that it transports the separately developed modules through kiwifruit orchards. Thus, in order for the unit to be successful in its own right, it only needs to demonstrate the ability to navigate through kiwifruit orchards

autonomously.

## 2. Review

An autonomous vehicle used to spray individual plants whilst driving at  $2.5 \text{ km h}^{-1}$  is published in 1998 (Tillett et al., 1998). It used wheel encoders, a compass, and accelerometers for odometry information. Row guidance was provided by way of a camera based machine vision system. The author notes that variability in lighting and the environment itself are responsible for the lack of commercial ready products before this time.

(Pedersen et al., 2002) presents an Ackermann based autonomous robot designed for weed mapping that has a top speed of  $6 \text{ km h}^{-1}$ . It used a GPS system to determine the absolute position of the vehicle at semi-regular intervals, with a gyro and compass used for odometry estimates between updates. This vehicle is designed to follow pre-defined paths through row-crops, but the authors find that this is not practicle without a separate row detection sensor.

Blackmore et al. discuss requirements for autonomous vehicles for agricultural use (Blackmore et al., 2004, 2007). These works highlight the benefits of light weight vehicles when soil compaction is an issue, however this is less relevant to orchards.

In 2004, (Bak & Jakobsen, 2004) present a relatively advanced robotic platform based on a four wheel steering. It is 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 odometry. However, it also featured encoder feedback and a row detection sensor, both of which were missing from Pedersen's unit. Additionally, the GPS unit used here utilised Real Time Kinematic (RTK) corrections from a base station. RTK-GPS is capable of providing positioning with accuracies down to 2 cm (Durrant-Whyte, 2005). This unit utilised a Controller Area Network (CAN) bus for some system communication.

In 2008, Klose et al. publish a paper presenting 'Weedy', a autonomous weed control robot for field use. The robot appears to have a relatively unique drive system whereby the angles of the front two wheels are controlled by a single stepper motor, as are the rear. 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 modules.

The following year, most of the same authors from the ‘Weedy’ paper published details an autonomous robotic platform with four wheel steering - 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 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.

Most relevant is the previous 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, referred to as ‘ATP’, to which for fruit harvesting arms were integrated.

A common theme among these vehicles appears to be 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 redundancy of having multiple sensors, into a single computation space. One such sensor is the RTK-GPS unit, appearing on the platforms published after 2004. With regards to its use in place of machine vision 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). This requirement can not be satisfied under the dense canopy of a kiwifruit orchard which are generally surrounded by thick, and tall wind-breaking hedges. Also, 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).

The popularity of the CAN bus for low-level communication is evidenced by its increasing frequency of usage over these developments.

### 3. Mechanical design

Skid steering inappropriate for orchard environments due to soft ground. Pivoting front axle used to maintain three points of contact at all times; no suspension. Limited to  $10 \text{ km h}^{-1}$  by the choice of motor and gearboxes on the drive-system. Operational speed of  $5 \text{ km h}^{-1}$ . 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 out in a timely manner. In the event that the synchronisation 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, written 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 developed 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]

## 8. Random info

“Field scouting and mechanical weeding have been identified and described as the first two niche tasks likely to become autonomous” (Blackmore et al., 2004).

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