A Platform for Autonomous Navigation in Kiwifruit Orchards

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Abstract

This will be written last. General tone of paper is: We present a vehicle designed specifically for autonomous control in kiwifruit orchards. Here are some other people who have made autonomous specific vehicles. Here is ours and this is how it fits in with those. We've gone with these sensors and this method of navigation and it has demonstrated itself to work in the orchard. We think that we could improve the thing by using this algorithm and increasing module space. Generally it is an improvement on the previous work of Scarfe.

Keywords:
Autonomous, Agricultural, Robotic, Platform, Lidar, Ackermann

1. Introduction

Short-term labor requirements within New Zealand's kiwifruit industry peak twice a year corresponding with pollination and harvesting. The majority of employment during these peaks is filled by seasonal or casual workers (Timmins, 2009). As kiwifruit is the country's largest horticultural export by value (Statistics New Zealand, 2015), automation in this industry may promote economic growth.

Previous work on automated harvesting of kiwifruit has been demonstrated (Scarfe, 2012; Scarfe et al., 2009). That work presents a mobile

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platform integrated with robotic arms that is capable of harvesting pergola type kiwifruit orchards. The platform presented in this paper is a second generation unit that increases modularity by separating the platform from the tasks it performs. This work discusses only the base platform, where details of modules for harvesting and pollination are published separately (Williams et al., 2017; Seabright et al., 2017).

Automation in kiwifruit harvesting and pollinating demands computer control, state-of-the-art manipulators, and convolutional neural networks. These systems are bulky and have specific geometric requirements dictated the environment and the tasks they perform. They share the requirements of transport to and from orchards, electrical power, and air pressure, but differ in they way they move when in the orchard. The pollinating module moves at a well-known velocity with minimum changes in angle, whereas the harvester advances a set distance between stationary harvest cycles. The duration of a 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 between cycles.

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 separation. The platform presented here simply needs to transport task specific modules autonomously through kiwifruit orchards.

The development of autonomous vehicles in agriculture is not new, but much of the literature relates to existing vehicles converted to driverless. This paper focuses on the development of a purpose built platform for the purpose of carrying robotic modules through an orchard environment.

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. Their vehicle combined wheel encoders, a compass, and accelerometers for odometry information, and featured a camera based row guidance system.

Figure 1: The robot platform driving through a kiwifruit orchard.

It was capable of spraying individual plants whilst autonomously driving at $2.5\,\mathrm{km\,h^{-1}}$.

In 2002, two autonomous robots designed for weed mapping and control were published (Pedersen et al., 2002; Åstrand & Baerveldt, 2002). The platforms in these works were relatively simple in terms of their design, referring only to the chassis and drive system, as they are still in a prototype stage. Both were Ackermann based and designed for field crops. The vehicle presented by Pedersen et al. (2002) was designed to follow pre-defined paths through row-crops, but the authors found that this was impractical without a dedicated row guidance sensor. They proposed a revision of their prototype that featured four wheel steering and drive system and integrating both GPS and a row guidance measurements. This work demonstrates a need to combine data from multiple sensor types, which becomes the standard henceforth. Mention at this time was made of utilising a Controller Area Network (CAN) to communicate with drive and steering modules on the revised unit due to it being a dominating standard in agricultural vehicles. Did this next prototype ever get published?

Bak & Jakobsen (2004) present 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 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 into a single computation space. With regards to the use of RTK-GPS in 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 requirement can not be satisfied under the canopy of a kiwifruit orchard which are usually 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). While Li et al. (2009) concludes that either GPS and machine vision, or GPS and lidar will be used together as a development trend.

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.

3. Mechanical design

The canopy of a kiwifruit orchard ranges between 1300 mm and 1700 mm. Modules designed to be carried by the platform require clearance from the canopy, in addition to to height they occupy themselves. To maximise space available to these modules the platform must be low-slung at the point of attachment. Figure 2 illustrates the design, with module area allocated between markers 'F' and 'E' in the side view (top left). The height of the chassis in this region is 360 mm from the ground.

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 steering, particularly at extreme steering angles. Each steering wheel has the freedom to rotate 340°, limited by a mechanical stop. This range of steering angle allows the vehicle to place the centre of rotation between its rear wheels. At this angle, the turning circle is equal to approximately twice the length of the vehicle. Implementing four wheel steering would allow the centre of rotation to move

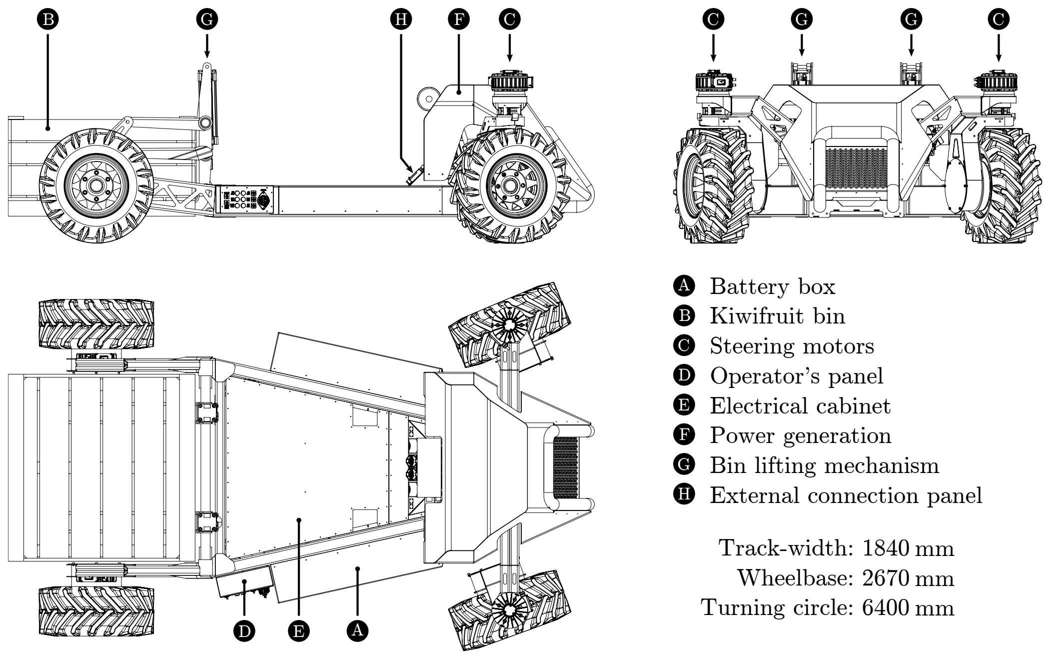

Figure 2: Profile drawings of the robotic platform with kiwifruit bin.

to the centre of the vehicle, decreasing the turning circle to the total length of the vehicle. However, headlands in kiwifruit orchards are sized for tractors to turn between rows, tractors which use Ackerman steering geometries. The implementation of Ackermann geometry on the platform simplifies the mechanical design, removes the need to develop "non-trivial" control strategies, and increases the usable area. A differential drive, or skid steer, system was expected to cause ground damage to a level considered unacceptable to orchard owners.

Bin lifting forks has been fitted to the area between the rear wheels. This area is sized to accommodate a standard kiwifruit bin. The lifter is actuated by two vertically mounted pneumatic cylinders and is controlled by a standard pneumatic valve block. This allows the platform to pick-up and drop-off bins as necessary while operating in the orchard; a task expected to be automated in future.

Other than its tires, the platform has no suspension. It features a front pivoting axle that ensures that a minimum of three wheels are always in contact with the ground. Each wheel is mounted directly to a 40:1 fixed ratio planetary gear gearbox connected to a permanent magnet, brushless AC motor. The gearbox-motor combination allows the platform to travel at a maximum speed of $10\,\mathrm{km\,h^{-1}}$. At this speed in an orchard a full suspension system is unnecessary. In total, the drive system is capable of delivering $25.6\,\mathrm{kW}$ of power and $3.3\,\mathrm{kN\,m}$ of torque continuously. With these specifications it is capable of accelerating from a stand-still to its maximum speed at an incline of $20°$ whilst carrying a $600\,\mathrm{kg}$ payload in $2.0\,\mathrm{s}$.

At the front of the platform sits a power generation unit including a petrol engine, air compressor, and alternator. The drive shafts of each are connected by a timing belt. The compressor and alternator are activated electronically by an embedded controller module. Fuel and compressed air tanks sit over the right-hand rear wheel; both are visible in figure 1. Battery modules attached to the sides of the chassis each house fifteen lithium-iron-phosphate batteries.

Unloaded, the machine has an estimated mass of $850\,\mathrm{kg}$, including the power generation unit. It is capable of carrying a $1000\,\mathrm{kg}$ payload. The mass of a standard bin of kiwifruit can be as much as $400\,\mathrm{kg}$, leaving $600\,\mathrm{kg}$ for modules.

4. System Architecture

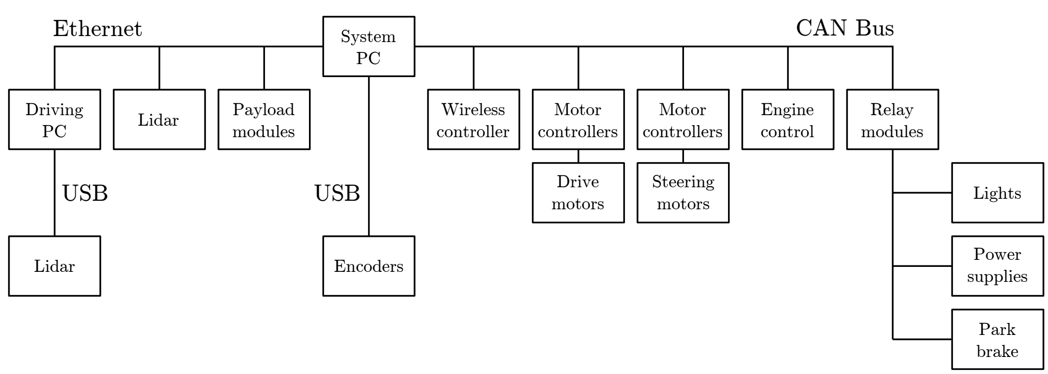

Figure 3: Hardware level system diagram showing the types of interfaces and relative relations on the platform.

Sub-systems on the platform, including the drive system, are connected to the system PC via a CAN bus, as shown in figure 3. The CANopen protocol has been implemented which offers message type prioritisation and a standardised way of sharing process data. Messages on the bus during operation are restricted to commands, syncronisation messages, and status updates. Relay modules connected to the bus allow the system to control the power to its on-board power supplies, motor controllers, park brakes, and lights. They also monitor the timing of synchronisation messages transmitted by the system PC and will enter an error state if the timing falls outside set limits. These messages must be transmitted every 20 ms, with a maximum allowable error of ±5 ms check these figures. Entering an error state results in the motor controllers being disabled, park brakes engaged, and power to the power supplies being cut.

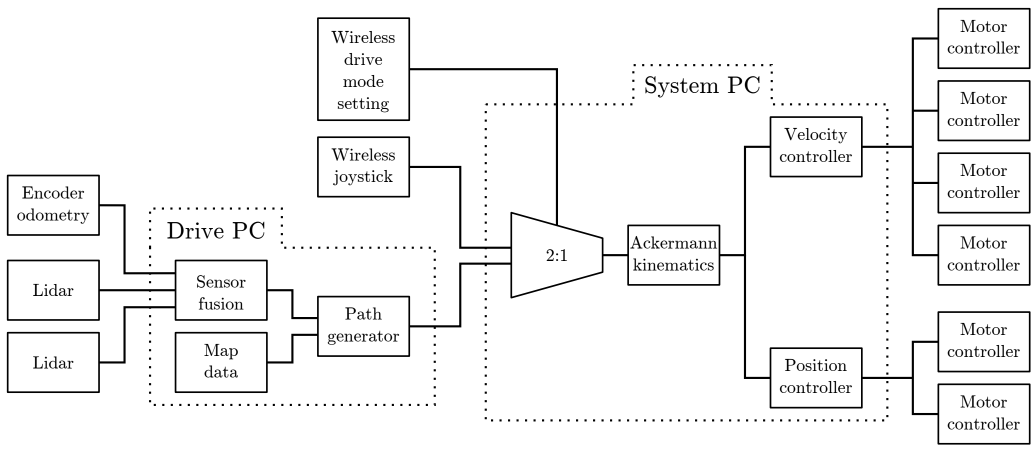

Figure 4: High level system diagram showing software architecture

A computer dedicated to processing sensing data related to navigation is connected to the platform's "System PC" via Ethernet. The open source Robotic Operating System (ROS) is used to facilitate communicate between the two computers. Not only is ROS used for inter-computer communication, but also within separate software nodes running on the same machine. Figure 4 shows the flow of data from various sources to the motor controllers. For simplicity it omits interface nodes, those used solely to interface the device to the ROS network.

To maximise code reusablility, each device on the platform has its own node dedicated to publishing device data or subscribing to generated device commands. Examples of such devices are CAN adapters, motor controllers, wireless controllers, lidar, encoders. Nodes are also used to transform or perform calculations on available data as well as pass it between nodes written in either C++ or Python.

In addition to the drive commands generated by the "Drive PC", a safety rated wireless controller lets the operator generate commands by joystick. The controller also has a mode selector that selects which commands are fed through to the motor drivers. An emergency stop button on the controller means that the platform can be stopped at any time.

5. Sensor selection

[Jamie's section]

6. Autonomous Driving

It would be great if we could put something in here with regards to how well the platform navigates an orchard. If you don't want to write it, I can write something generic and put it in for you to approve. Alternatively, you may not want anything in here relating to the navigation performance.

Figure 5: Photo showing the platform performing a row-end turn

7. Discussion

TODO: Generally summerise the platform, its ability to carry stuff, suitability for the orchard environment, and its ability to drive autonomously.

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8. Jamie-Mark communication

You are free to suggest anything about anything. Maybe you want to add someone to the authors list? Maybe you don't like the focus of the review, or think a review is not necessary. Perhaps you can think of something that would go well in the paper that I've not mentioned.

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