Automated pollination of kiwifruit flowers

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Abstract

This paper contains the initial evaluation of a novel platform mounted robotic pollination system. Advancement in artificial pollination is an important step forward in agricultural sectors due to the global decline of natural pollinators. Robotic pollination allows for potentially autonomous, precision operation; however, background research suggests prior development in the area is sparse. The featured wet-application robotic pollination system can detect 89.3% of flowers, correctly localise 71.9% of flowers and hit an estimated 80.1% whilst driving at a 0.36 m/s through kiwifruit orchard rows.

Key words – Pollination; Robotics; Detection; Kiwifruit; Horticulture

Background

Kiwifruit are New Zealand's largest horticultural export, worth over US$1.25 billion in annual revenue (Statistics New Zealand, 2016). The yield from kiwifruit orchards is particularly sensitive to the presence of bees for pollination. A lack of bees for kiwifruit flower pollination that has led to a range of commercial, artificial pollination processes. Companies in the Bay of Plenty, provide artificial pollination services to kiwifruit orchards by blowing dry pollen into the canopy using modified quad-bikes, as shown in Figure 1. Typically, they can pollinate one hectare per hour with approximately 700 g of dry pollen. This method is augmented by bees, introduced in portable hives, to help spread the pollen to the flowers. Hayward Kiwifruit require 2,000 – 12,000 pollen grains/flower to produce export quality fruit (Hii, 2004). A non-bee method is the Cambrian sprayer, also shown in Figure 1. This method uses pollen suspended in a liquid solution that is then spray directly onto individual flowers. This method consumes approximately 1-1.2 kg of pollen per hectare.

Figure 1. A dry pollen application system (left) Wet pollen spray application system (right)

There is growing interest in replacing bee, manual, and crop dust pollination with robotic systems that can deliver the required pollen directly to the flower. It is theorised that for commercial viability, a robot will need to pollinate a hectare of kiwifruit orchard with between 500 g and 800 g of pollen. A modern, well managed orchard, can contain more than 500,000 flowers per hectare. Kiwifruit rows are typically 4-5 m wide and contain approximately 300 flowers per linear metre. Typical pollen suspensions are 4 g of pollen per litre of liquid for hand pollination. With a kiwifruit flower's stigma bush in the order of 20 mm in diameter, this equates to a volume of 650 µL of pollen suspension at 8 g/L concentration being delivered to each flower. For a robotic pollination system to operate at a ground speed of 1.4 m/s and provide similar service to hand pollination, a robotic pollinator would need to deliver this volume from a distance of 200-400 mm within a period of 50 ms. Measurements of flower detection, localisation and targeting accuracy using a robotic system are reported.

Methods

Flowers are identified using machine vision as the kiwifruit pollination robot passed under the canopy. The flower's position, together with the robot's velocity, is used to select a nozzle to fire and to time its activation in order to spray the individual flower. The pollen suspension medium is pressurised to approximately 200 kPa. A circulation pump keeps the solution moving through the spray manifold, while a motorised stirrer maintains the pollen-liquid emulsion within the mixing/storage tank.

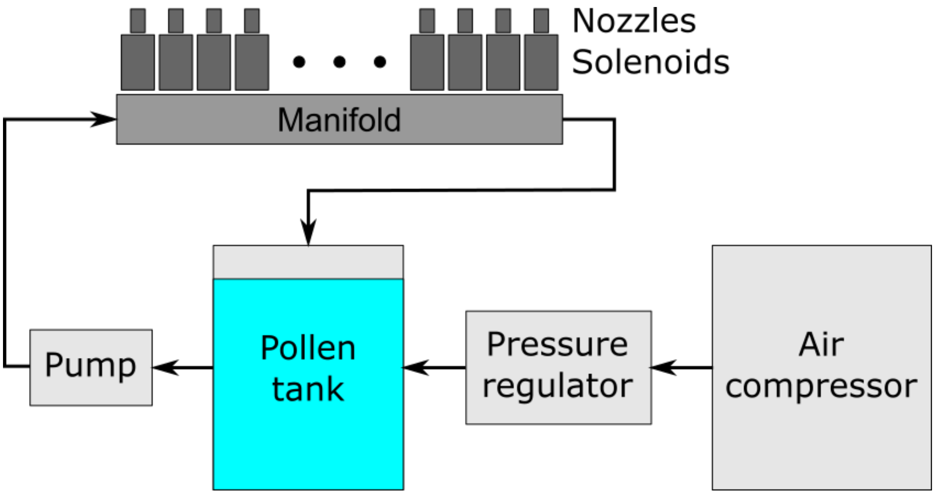

Figure 2. Wet pollination system schematic

For a typical kiwifruit orchard, this requires a 4-5 m wide spray boom with between 320 and 500 nozzles. Laboratory experiments with cultivated flowers proved that the most effective actuation time for the solenoid controlled nozzles is 50 ms. Previous trials showed that one long spray boom is impractical due to its high mass, poor manoeuvrability, and inability to maintain a constant distance from the canopy. Since the vertical position of kiwifruit flowers can vary substantially both across a row and along it, multiple shorter booms with individual height adjustment were trialled. Each of these booms are actuated using a ball-screw actuator that provides a vertical stroke of 400 mm and can move across its full range in 0.8 s. Each boom segment is 500 mm wide with 40 nozzles placed at 12.5 mm spacing. The tested system contains two booms as shown in Figure 3.

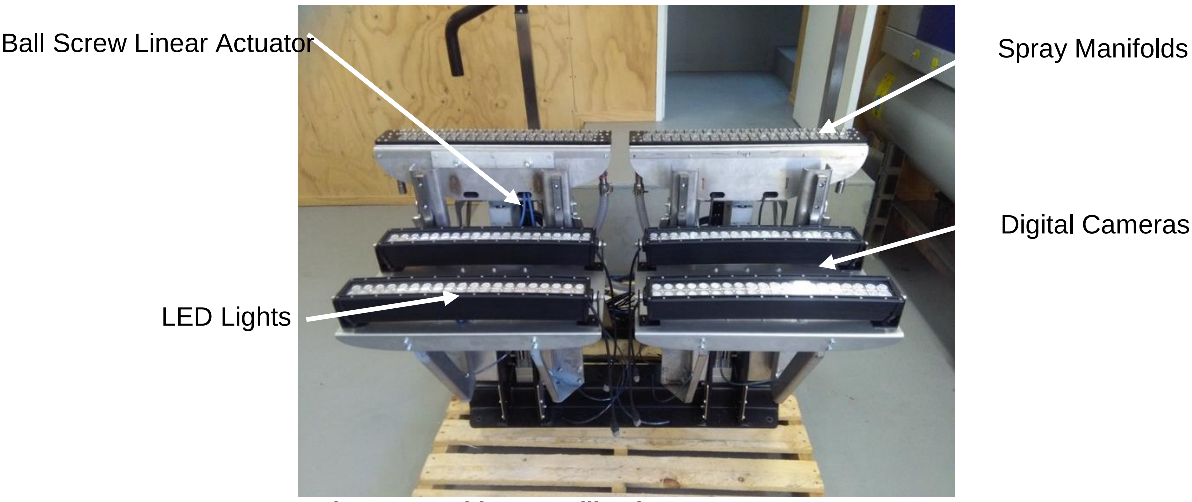

Figure 3.Dual-boom pollination system

Each spray manifold is equipped with a pair of digital cameras and dual 200 W LED light bars. The cameras are mounted to the boom and hence move as the boom is adjusted. A LiDAR unit mounted forward of the pollination system is used to detect the canopy's height as the unit drives through the rows. Algorithms controlling boom height keep each boom approximately 150 mm from the canopy. At the software level, the pollination system is controlled via the ROS (Robot Operating System) framework and image processing was achieved through a CNN (Convolutional Neural Network), which can detect 95% of kiwifruit flowers. A sample image of flowers detected using the CNN method is shown in Figure 4.

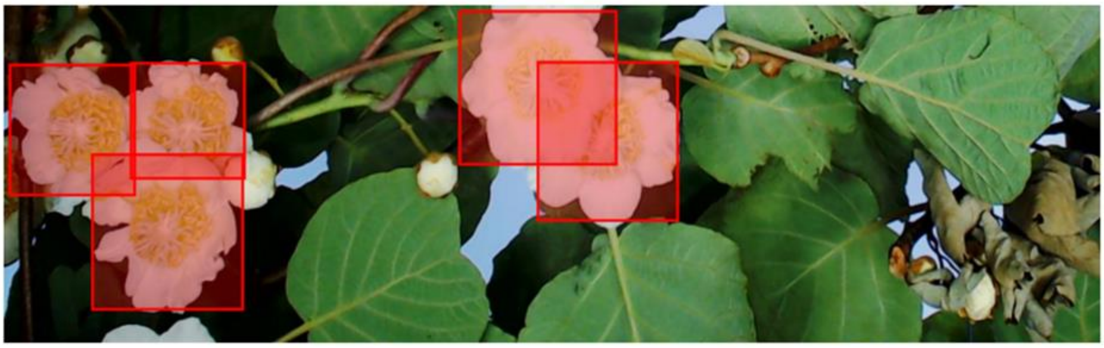

Figure 4. Kiwifruit flowers identified using a convolutional neural network

A base robotic platform was developed in parallel with the pollination booms that is used to move the pollination system through the orchard. The platform, shown in Figure 5, is a second-generation prototype developed from work done previously (Scarfe et al., 2009). It is a four-wheel drive series-hybrid. It uses six hub mounted electric motors with built in gearboxes; four as traction drive units and two for steering. A petrol generator recharges the batteries during operation and supplies compressed air to the system. The platform has variable speed control up to 10 km/h and can operate over a range of agricultural terrain. As each of the wheels are individually controlled, the unit has the capability of pivoting about the centre of its rear wheels. This makes it well suited to an orchard environment where tight turns are required between rows.

Figure 5. The base robotic platform sitting in an orchard

Calibration tests were used to determine sequence timing when firing nozzles. These timings allow the forward velocity of the platform to be accounted for when firing a shot. Tests also identified the range of practical speeds the system can drive at to accommodate image processing and spray nozzle activation times required.

Figure 6. Pollination system mounted on the platform (in orchard)

Results and discussion

The neural network based vision system was evaluated over two orchard trials conducted in two different orchards, one during the day and the other at night. Overall, 89.3% of the 1584 flowers visible in the images were detected, with 8 false positives. A comparison of detection performance between day and night-time use showed an insignificant difference.

The stereo matching system correctly matched 80.5% of the correctly detected flowers. It found an incorrect match for 6.6% of the flowers and failed to match for the remaining 12.7%. Matching performance was better during the day than at night with 83.0% correctly matched during the day versus 77.5% at night.

Combining the detection system and stereo matching results, we can see that 71.9% of visible flowers were correctly localised.

The spraying accuracy was evaluated over five trials in a single orchard with the base platform moving at a different velocity for each trial. At the slowest velocity of 0.22 m/s, 218 flowers were hit while 336 shots were fired. This means that 0.65 flowers were hit per shot fired. This decreased as the velocity of the base platform increased with the maximum speed of 1.3 m/s resulting in 0.37 flowers hit per shot fired. Video footage suggests that at higher ground speeds, many shots were missing due to late firing. This points to errors in the firing scheduling system, the spray trajectory models or the velocity feedback used.

An overall flower hit-rate is difficult to evaluate as the ability to count flowers only within the spraying window of the nozzles based on video footage is not possible. However, an estimate of 587 flowers hit out of a total of 732 with the base platform traveling at 0.36 m/s has been made. This gives a hit rate of about 80%, although this result is higher than the proportion of flowers correctly localised (71.9%). Video suggests that this could be due to flowers being hit unintentionally. This is because kiwifruit flowers tend to grow in small, high-density clusters surrounded by areas of very low flowering density. Firing at flowers in a high-density cluster often results in neighbouring flowers also being hit.

Conclusions and future work

Natural pollinators are of economic importance to the fruit industry, but their populations are declining to the point of being unable to provide comprehensive pollination in intensive crop environments. Artificial pollination is a method of replacing or supplementing this. Typically performed manually, or by way of mechanical sprayer, artificial pollination is currently in use throughout the world. Robotic pollination is a progressive variation whereby autonomy and precision operation can aid in removing the human labor requirement from artificial pollination.

In this paper, a robotic kiwifruit pollinating system was trailed with a design specification that enables commercially viable operation. In its current form the featured system is not able to meet these specifications, but it is expected that future work will enable its viability. Notable results are: its ability to detect 89.3% of flowers, localize 71.9% and hit an estimated 80.1%. Future work will include scaling the number and/or size of manifolds to accommodate a full orchard row width of 4.5 m, optimization of machine vision software, and shot accuracy such that the system can offer a commercially viable solution.

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