Development of an Autonomous Kiwifruit Harvester

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Abstract

The already intensive labour requirements within the New Zealand kiwifruit industry are increasing. Furthermore, ZESPRI Group Limited is targeting a threefold increase in industry return by 2025 (from approximately $NZ1Billion to $NZ3Billion). Development of autonomous mechanised solutions to assist manual labour is emerging as a strategic necessity.

The objective of this research was to develop a commercially viable autonomous kiwifruit harvester (AKH). The AKH must be capable of operating within variable and complex on-orchard environments to minimise manual labour requirements. Successful completion required development and integration of autonomous:

1. Fruit identification and localisation
2. Custom robotic arms with soft fruit extraction harvesting hands
3. Custom robotic arm for soft fruit handling
4. Transportation platform with navigational sensing and strategies
5. Storage bin collection and drop-off

The AKH has four robotic harvesting arms with hands specifically designed to mimic the human fruit harvesting action. Remotely mounted stereoscopic vision identifies and localises fruit. The fruit locations are mapped into the harvesting arms' coordinate space allowing fruit extraction. The presented system configuration resolves the slow harvest rates experienced by other systems. Practical on-orchard testing identified additional environmental complexities that present the greatest challenge to consistent fruit identification. These are mainly from natural lighting effects.

Stereoscopic machine vision (SMV) was investigated as the primary navigation sensor. However, diverse environmental conditions (lighting and structure appearance) made consistent object detection unreliable. Consequently, a light detection and ranging/SMV combination was used to achieve reliable navigational object detection and fruit storage bin identification.

Practical on-orchard testing and analysis verified AKH operational ability (testing was limited due to a vine killing bacterial (Psa-V) outbreak restricting orchard access):

1. Fruit identification (83.6% of crop) with combined localisation and extraction accuracy of 3.6mm in three-dimensional space
2. More gentle fruit harvesting and handling than humans harvesting
3. Reliable object detection and path planning for navigation. Over the twenty metre scanning range 96% of the in-row objects were correctly classified to reliably determine the drive path
4. Reliable fruit storage bin identification and localisation (98% correct classification)
5. Commercially viable manufacture cost less than $130,000 per unit
6. Although full commercial operation was not achieved, modifications are identified to rectify the limitations

Key system improvements are presented for:

1. High intensity artificial lighting for increased fruit identification rates. Natural sunlight variations affected identification ability, minimising this affect will increase identification rates
2. Alter the storage bin filling arm geometry to permit complete storage bin filling
3. Sensing the robotic arms' position to resolve positioning errors

Acknowledgements

Several individuals and organisations have contributed to and made this research project possible,

1. The author especially acknowledges Dr Rory Flemmer (SEAT, Massey University, Manawatu, New Zealand). Dr Flemmer provided core technology used to development the Autonomous Kiwifruit Harvester. This included:
    a. A patented robotic manipulator design (Flemmer, 2009). His concentric driveshaft design allowed low-cost stepper motor drive and position feedback using hall-effect sensors. It was used on both harvesting and fruit handling manipulators. He also provided skeleton control code which formed the basis for higher-level control strategies and customised picking motion. The provided control code contained methods to:
        i. Efficiently step each motor
        ii. Produce linear robot motion between two points

        Both manipulators kinematics (harvesting and bin filling) and custom movements were developed to increase functionality and efficiency. These were added to the initial control code by the author.
    b. Epipolar geometry for stereoscopic depth perception. This geometry included a method to calibrate and determine both extrinsic and intrinsic camera properties. This method allowed absolute distances to be calculated.
2. Dr Huub Bakker and Associate Professor Donald Bailey (supervisors) as well as Associate Professor Stephen Marsland and Professor Don Cleland, who supported, guided and shared knowledge with the author to complete his studies.
3. Plus-Group Horticulture Ltd funded the prototype robotic harvester from concept. Managing director Steve Saunders provided key industry knowledge and experience pertinent to successful on-orchard operation.
4. ZESPRI Group Ltd provided funding for the completion of dual robotic arm picking and storage bin filling (ZESPRI Project PE1059). ZESPRI Group Ltd also provided financial support and guidance through their Innovation Fellowship.
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7. Dr Huub Bakker, Clive Bardell, Andrew Booth, Kyle Peterson, Colin Rose and Mike Lusby were involved with the project during development. Their involvement ranged from CAD modelling, fabrication, machining, wiring and assembly of components and systems. While working on the project they were under the author's supervision. The author directed design, development and management decisions during this process but wishes to acknowledge and thank them for their assistance.

Key Contributions

As a team helped with this project, the author has commented on the team members' contribution throughout this thesis. During development, the author managed and supervised the work of those other contributors. He directed design decisions and development through the process. This team assisted during the first year of development.

Within this team, the author's key contributions are the:

1. Fruit identification system
2. Improvement to the stereo vision system and its calibration
3. Improvement and implementation to the hand-eye coordination system. This includes the calibration device for the robotic arm and locating its position to sub-pixel accuracy with the vision system.
4. Development of the harvesting hands (each generation).
5. Modifications to the initial robotic harvesting arm design. This included: Improvements to the arms kinematic models and development of the custom motion paths; the parallel linkage system to keep the hand vertical, remote mounting of the hands actuators and some structural refinements.
6. Development of the collision detection, avoidance and harvesting scheduling systems.
7. Bin filling robot design and development.
8. Autonomous Transportation Platform. This included: programming the drive system; traction control; custom manoeuvres; chassis and bin lifter design; the initial vision work for navigation; development and implementation of all LIDAR based systems for navigation and bin fining; as well as the integration of the vision and LIDAR systems.
9. A significant amount of general fabrication, machining, construction, wiring, etc.

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Worker harvesting kiwifruit from a T-bar growing system. Photo courtesy of Plus Group Horticulture.