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[F] PhD Extended Abstract Form *(Please select the Calibri 10 typeface)*

FULL PhD THESIS TITLE: AN AUTONOMOUS IMMATURE GREEN CITRUS FRUIT YIELD MAPPING SYSTEM

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Extended Abstract

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1. Chapter 1

Title : Introduction

This research project focused on developing an autonomous robotic system for immature green citrus fruit yield mapping. The overall goal was to create a robotic system to count fruit more effectively and estimate citrus yield with less effort. In Chapter 1, I briefly introduced citrus production information and the current citrus yield forecast procedure. Then, I reviewed the existing robotic systems that have been developed in agriculture. In the end, I discussed the necessity of developing such a system and specific objectives of the project.

2. Chapter 2

Title : System Overview

Yield mapping is considered as an initial step for applying precision agriculture technologies. Although many yield mapping systems have been developed for grain crops, it remains a difficult task for mapping yield of tree crops. In this study, an autonomous immature citrus yield mapping system was developed. The system could detect fruit and create yield maps at early growth stages of citrus fruit so that farmers could apply site-specific management based on the maps. There were two sub-systems, a navigation system and an imaging system. Robot Operating System (ROS) was the backbone for developing the navigation system using an unmanned ground vehicle. An inertial measurement unit (IMU), wheel encoders and a GPS were integrated using an extended Kalman filter to provide reliable and accurate localization information. A LiDAR and a Kinect camera were added to support simultaneous localization and mapping (SLAM) algorithms for autonomous navigation of open fields and citrus groves. A multimodal imaging system, which consisted of two color cameras and a thermal camera, was carried by the vehicle for video acquisitions. Multimodal registration and information fusion algorithms were developed to combine information from color and thermal cameras. Faster R-CNN and optical flow algorithms were applied to detect and count the fruit in real-time. The system is expected to improve the accuracy of fruit detection to approximate 90%.

3. Chapter 3

Title : The Autonomous Navigation System

Autonomous navigation as one of the robots' abilities, could save labors for driving vehicles and provide accurate and consistent localizations to perform farm operations. The goal was to develop a navigation system that could guide a field robot to travel from a farm station to a citrus grove and visit each tree autonomously with obstacle avoidance ability. The system was developed with consideration of the concept of future smart farms, in which internet of things and big data analysis would be implemented.

Most studies of orchard navigation have focused on single row guidance or single orchard navigation (row-following plus turning) rather than attempt to solve the problem to navigate vehicles autonomously in an entire farm. Thanks to the recent advance of technologies, such as internet of things (IoT), deep learning, and big data, creating smart farms has become a popular research topic. In chapter 3, a navigation system was developed to guide a ground robot to travel from a farm station to a citrus grove and guide it to automatically follow each row of the citrus grove while avoiding all obstacles encountered. The sensor data and the robot's status were monitored and recorded from the farm station in real-time. The system also enabled the computer at the farm station to interrupt and control the robot manually in emergency scenarios. The communication between the robot and the farm station was established under a Wi-Fi network, in which more sensing systems could be added easily.

4. Chapter 4

Title : A Photogrammery-based Image Registration Method for Multi-camera Systems

In precision agriculture, estimating crop yield using remote sensing techniques is an active research field. To achieve high accuracies, researchers frequently combined different imaging sources, such as colour (RGB) images, thermal images, and near-infrared images. However, fusing information from those images has been a difficult task. Therefore, accurate image registration methods are necessary. This study aimed to develop a thermal-colour camera system which will register thermal images with colour images of tree canopies in preparation for information fusion and fruit detection. The registration method created in this study was based on photogrammetry. In preparation of registration, a camera system was built, consisting of a thermal camera and two colour cameras. Camera calibration, image intersection, and space resection were combined in a single step named 'stereo-calibration', to compute cameras' parameters and poses. Speeded-up robust features (SURF) were used to find points of interest from colour images. Random sample consensus (RANSAC) was utilised to search for optimal homography transforms between thermal and colour images. In addition, this study created a procedure for accurate registrations of regions of interest in thermal-colour image pairs, utilizing structural similarity (SSIM) index. The proposed method offered pixel-level registration accuracy and achieved an average accuracy of three pixels in 640 × 480 - pixel citrus canopy images.

5. Chapter 5

Title : Immature Green Citrus Fruit Detection using Color and Thermal Images

Citrus fruit detection is one of the most important and challenging steps in citrus yield mapping. The distinct color differences between the ripe fruit and leaves allowed previously-described imaging-based methods to achieve good results. However, immature green citrus fruit detection, which aims to provide valuable information for citrus yield mapping at earlier stages is much more difficult because the fruit and leaf colors are very similar. This study combines color and thermal images for immature green fruit detections. Experiments identified optimal conditions for thermal imaging. A multimodal imaging platform was built to integrate color and thermal cameras. A novel image registration method was developed for combining color and thermal images and matching fruit in both images. A new Color-Thermal Combined Probability (CTCP) algorithm was created to effectively fuse information from the color and thermal images to classify potential image regions into fruit and non-fruit classes. Algorithms were also developed to integrate image registration, information fusion and fruit classification and detection into a single step for real-time processing. An increase in recall rate from 78.1% when using only color images to 90.4% after fusing the color and thermal images was obtained at similar precision rates, and an increase in precision rate from 86.6% to 95.5% was obtained at similar recall rates. The fusion of the color and thermal images effectively improved immature green citrus fruit detection.

6. Chapter 6

Title : An Active Thermography Method for Immature Fruit Detection

In this chapter, the study explored a novel active thermal imaging method to tackle the problem of color similarity between immature citrus fruit and leaves. A thermal camera was combined with a water spray system that applied water mist to citrus trees. The water mist caused temperatures of both the fruit and leaf surfaces to change but at different rates. Multiple parameters of the spray system were experimentally studied with the goal to induce as much temperature differences as possible between fruit and leaf surfaces. The combined system was tested in a citrus grove for fruit detections. Deep learning models were built based on the active thermal imaging system and tracking and fruit counting algorithms were created to count fruit in thermal videos. A mean average precision of 87.2% was achieved by the models and an accuracy of 96% was achieved when comparing the number of fruit counted by the algorithms with the true number of fruit counted manually in the field.

7. Chapter 7

Title : System Integration and Evaluations

The goal of system integration was to combine the navigation system and the multi-modal imaging system for immature citrus fruit yield mapping. The integration would allow the system to work in three different modes in a citrus grove: (1) real-time yield mapping using a color camera; (2) real-time yield mapping using a thermal camera; (3) post-processing for yield mapping using color and thermal cameras. The accuracy of the fruit counting algorithms was evaluated by comparing the total number of fruit counted by the algorithm and the number of fruit counted from non-overlapping video frames, NIVF, which provided a rough estimation of the accuracy of the fruit counting algorithms. Work was done to (1) integrate multiple sensors to provide precise localizations; (2) combine and synchronize all the sensors on both the navigation and imaging system; and (3) detect and count the number of fruit from color and thermal videos in real-time.

8. Chapter 8

Title : Conclusions and Future Studies

In this research, different components and functions necessary for developing an immature citrus fruit yield mapping robot were studied. Major components are the navigation system and the imaging system and major functions included autonomous navigation, multi-modal image registration and information fusion, and fruit counting and yield-generating.

The ultimate goal is to develop a market-ready immature citrus yield mapping system. While this research explored most of the components for building a functional system, there are still challenges on the way to make the system ready for commercial usage. Future studies may include (1) using deep learning method for recognizing scences from the vision system to assist navigation, (2) developing parallel computing algorithms for multi-modal image registration to increase processing speed, and (3) designing low-cost and rugadized system for commercial deployment.

Final remarks concerning the competition benchmarks and strength points

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This study focused on developing an autonomous robotic system for yield mapping of specialty crops. The successful development of such a system will greatly reduce the labor and improve accuracy for data collection. The system can be integrated with other mobile and in-situ sensors to form the agriculture internet of things (IoT). Breakthroughs in the area of agricultural robots will be critical for promoting IoT systems and big data analysis for next-generation agricultural production systems.