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Research Paper

A photogrammetry-based image registration method for multi-camera systems – With applications in images of a tree crop

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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 (Red, Green, Blue [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 of 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, utilising structural similarity (SSIM) index. The proposed method offered pixel-level registration accuracy and achieved an average accuracy of 3 pixels in 640 × 480 – pixel citrus canopy images.

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1. Introduction

Image registration has been frequently applied for combining images in a multi-modal imaging system. Richer information could be obtained through image registration for solving problems such as object detection and classification. In agriculture, yield mapping of orchard fruit requires accurate fruit detection using remote sensing techniques. However, many fruit detections suffered on accuracy in the past because analysing images of complex tree canopies under various illumination conditions is extremely difficult (Kurtulmus, Lee,

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Nomenclature

a1	Position of point A in image plane 1
a2	Position of point A in image plane 2
CFL	Calibrated focal length
K	Intrinsic matrix of the thermal camera
IR	Infrared
O1	Principal point of camera 1
O2	Principal point of camera 2
PHA	Polyhydroxyalkanoate
PLA	Polylactide
R	Rotational matrix of the thermal camera relative to the base camera
RANSAC	Random sample consensus
RGB	Red, Green, Blue
S	Scalar
SSIM	Structural similarity
SURF	Speeded-up robust features
T	Translational matrix of the thermal camera relative to the base camera
X_A	X coordinate of point A
Y_A	Y coordinate of point A
Z_A	Z coordinate of point A

& Vardar, 2011; Sengupta & Lee, 2014). Therefore, many studies have tried to create multi-modal imaging systems to overcome problems of imaging in agricultural fields. Among numerous multi-modal systems, thermal-colour camera systems are commonly used. Thermal and colour cameras detect two well-separated electromagnetic spectrum regions so that features detected by the two types of cameras will be less correlated. However, the effectiveness of applying thermal-colour imaging systems for orchard fruit detections has been limited because of lacking accurate image registration methods. The shapes of leaves and fruit appeared in the images can be random and complex. Therefore, developing an image registration method which addresses problems in orchard fruit detection is necessary.

Image registration can be classified into two types: feature-matching based registration, and photogrammetry-based registration. Feature-matching based registration has been studied for many years, and a lot of work have been published. Feature-matching based registration can also be divided into area-based and feature-based methods. Both groups registered images based on aligning same features presented in all images. The main difference between them is that area-based methods put more emphasis on feature matching than feature detection (Zitova & Flusser, 2003). To deal with multi-modal registration, similarity measures using correlation ratio (Roche, Malandain, Pennec, & Ayache, 1998), or mutual information by measuring cross-entropy (Viola & Wells, 1997) were developed. Feature-based methods aimed to find correspondences between images using spatial relations or descriptors of features (Zitova & Flusser, 2003). Lowe (1999) introduced an image feature descriptor that was invariant to image scaling, translation and rotation and partially invariant to illumination changes and a method for generating such features called Scale Invariant Feature Transform (SIFT). This descriptor had been widely used since it was invented. Recently, a new feature descriptor named speeded-up robot features (SURF) was created (Bay, Ess, Tuytelaars, & Van Gool, 2008). It was scale and rotation invariant and was proved to be much faster than SIFT. Registrations were based on matching features represented by those descriptors. Although many of those registration methods have been evaluated and proved to be effective, many of the methods were only designed for colour image registrations or aligning images generated from the same sensors. For multi-modal image registrations, such as colour-thermal image registration, those methods could hardly work. Figure 1 shows an example illustrating the differences of SURF features on colour and thermal images.

Most studies of image registration for thermal and colour images in literature also focused on feature-matching based registration, especially in the field of medical imaging and facial recognition. To register computed tomography (CT) and magnetic resonance images (MRI) of brains, Maes, Vandermeulen, and Suetens (1999) computed the mutual information of voxel intensities in both images and matched them by maximising the value. This method required that both images had similar intensity features and the computation speed was a limitation. Instead of comparing intensity features of images in multi-models, Chung, Wells, and Norbash (2002) utilised a learning method by building the *a priori* knowledge of the expected joint intensity distribution estimated from aligned training medical images. The study

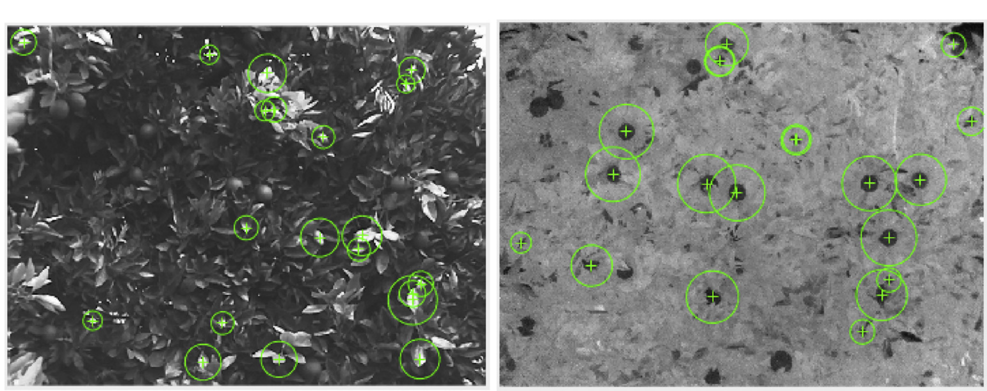

Fig. 1 – Top 20 SURF features (green circles) in a colour image (left) and a thermal image (right) of the same scene (tree canopy). The images show that the locations of the top 20 SURF features are very different in colour and thermal images.

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