UNIVERSITY OF TECHNOLOGY SYDNEY

Reconstruction of 3D Surfaces with Complex Material Composure Using a Light Field Camera

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under the supervision of A/Professor Stuart Perry

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Helia Farhood declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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DEDICATION

This PhD thesis is dedicated to my mother Pouran Hamidi
for giving me invaluable educational opportunities
and my husband Mohammad Najafi
for his support, constant encouragement and care.

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LIST OF PAPERS (PUBLICATIONS)

Helia Farhood, Stuart Perry, Eva Cheng, Juno Kim, "Enhanced 3D Point Cloud from a Light Field Image," Remote Sensing, vol. 12, p. 1125, 2020. Published in April 2020. Journal Ranking: Q1. (Related to Chapter 6)

Helia Farhood, Stuart Perry, Eva Cheng, Juno Kim, "3D point cloud reconstruction from a single 4D light field image," in Optics, Photonics and Digital Technologies for Imaging Applications VI, 2020, p. 1135313. Published in April 2020. (Related to Chapter 5)

Helia Farhood, Stuart Perry, Eva Cheng, Juno Kim, "Depth estimation: combination of sub-aperture matching and defocusing for a 4D light field", Elsevier, Pattern Recognition, February 2020 (under review). Journal Ranking: Q1. (Related to Chapter 4)

Helia Farhood, Stuart Perry, Eva Cheng, Juno Kim, "Reflection Recovery in Light Field images with Complex Material Appearance", has been submitted to Elsevier Journal of Signal Processing Image Communication, September 2020. (Related to Chapter 7)

Helia Farhood, Xiangjian He, Wenjing Jia, Michael Blumenstein, Hanhui Li, "Counting People Based on Linear, Weighted Local random Forest", The International Conference on Digital Image Computing, DICTA 2017. Published in December 2017.

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ABSTRACT

Representing real world objects on a digital screen is a significant and challenging topic in the area of computer vision and augmented reality. This work addressed the challenge of reconstruction of 3D surfaces with complicated material appearance by using a light field camera. Most recent research uses single images to address this problem, but without using a light field camera, encounter difficulties and limitations to overcome this problem. However, we show that by using a light field camera without user interaction or any requirement for object planarity or symmetry, reconstruction of a 3D model with high accuracy is possible. A light field camera, also known as a Plenoptic camera can capture rich information about the spatial and angular distribution, as well as intensity and colour of light in a single shot. Light field cameras can be used to improve the performance of traditional computer vision problems, such as depth estimation, post-capture refocusing, illumination estimation, and material estimation which are not easy for traditional methods with a standard image. For reconstruction of 3D models, creating a 3D point cloud is essential and is often obtained based on a depth map. As a result, first we developed a robust method to estimate an accurate depth map based on the combination of sub-aperture image matching and defocusing cues for a 4D light field format. The depth map is refined using a fast-weighted median filter providing robustness to noise. Therefore, the proposed approach compared with other state of-the-art algorithms can estimate depth of real-world images and challenging images more accurately. In the second part, we proposed a novel strategy for the creation of a 3D point cloud from the depth map of a single 4D light field image. The proposed method is based on the transformation of point-plane correspondences. Considering the estimated depth map from the previous part, we applied histogram equalization and histogram stretching to enhance the separation between depth planes. The suggested method avoids feature

extraction, segmentation and the extraction of occlusion masks required by other methods, and due to this, our method can reliably mitigate noise. In the third step, we improved our suggested method to obtain a dense and more accurate three-dimensional (3D) point cloud. We applied intelligent edge detection by using feature matching and fuzzy logic from the central sub-aperture light field image and the depth map. The results showed that our new method can reliably mitigate noise and had the highest level of detail compared to other existing methods. Finally, having obtained the 3D point cloud, we handled the problem of reflectance in complex material appearance. We developed a new strategy to recover reflectance information based on colour analysis as well as brightness analysis of a light field image. Our aim is to separate specular pixels by using two different strategies. On the one hand, we estimated light source colour from different angles of the RGB light field image to find specular pixels. On the other hand, we binarized light field sub-aperture images to obtain brightness areas in different viewpoints and extract specular highlights. Experimental results demonstrate the effectiveness of our method in both synthetic and real-world images compared to other state of the art methods. Overall, 3D reconstruction can cover many applications and solve many problems of computer graphics and computer vision that is still a challenging topic.