UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronics and Computer Engineering

DEVELOPMENT OF DOUBLE STAGE FILTER (DSF) ON STEREO MATCHING ALGORITHM FOR 3D COMPUTER VISION APPLICATIONS

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DEVELOPMENT OF DOUBLE STAGE FILTER (DSF) ON STEREO MATCHING ALGORITHM FOR 3D COMPUTER VISION APPLICATIONS

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A thesis submitted
in fulfillment of requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "Development of Double Stage Filter (DSF) on Stereo Matching Algorithm for 3D Computer Vision Applications" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Teo Chee Huat
Date	:	....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

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Supervisor Name	:	Nurulfajar bin Abd Manap
Date	:	....

DEDICATION

To my beloved family

ABSTRACT

In the field of stereo vision, some of existing stereo matching algorithms are designed with less accuracy of algorithm. Thus, a new hybrid algorithm with higher accuracy of computation is developed in this project. This thesis will present the design, development and analysis of performance on a developed Double Stage Filter (DSF) algorithm and other existing stereo matching algorithms. DSF algorithm is a hybrid stereo matching algorithm which divided into two phases. Phase 1 is consists of the part on Sum of Absolute Differences from basic block matching and the part of Scanline Optimization (SO) from dynamic programming approches while phase 2 includes segmentation, merging and basic median filter process. The main feature of DSF algorithm is mainly on the phase 2 or as post-processing in which to remove the unwanted aspects like random noises and horizontal streaks, which is obtained from the raw disparity depth map on the step of optimization. In order to remove the unwanted aspects, two stages filtering process are needed along with the developed approaches in the phase 2 of DSF algorithm. There are two categorized evaluations done on the disparity maps obtained by the algorithms : objective evaluation and subjective evaluation. The objective evaluation includes the evaluation system of Middlebury Stereo Vision website page, computation analysis and traditional methods of Mean Square Errors (MSE), Peak to Signal Noise Ratio (PSNR) and Structural Similarity Index Metric (SSIM). Besides, for subjective evaluation, the datasets are captured from LNC IP camera and the results obtained by the selected algorithms are evaluated by human's eyes perception. Based on the results of evaluations, the results obtained by DSF is better than the algorithms, basic block matching and dynamic programming.

ABSTRAK

Dalam bidang visio stereo, terdapat banyak rekaan algoritma padanan stereo yang kurang ketepatan. Oleh itu, satu algoritma hibrid baru dengan komputasi yang lebih ketepatan akan direka dalam projek ini. Tesis ini membentangkan reka bentuk, pembangunan dan analisis prestasi algoritma Penapis Gandaan Peringkat (DSF) dengan algoritma padanan stereo yang sedia ada. Algoritma DSF merupakan satu algoritma hibrid padanan stereo yang terbahagi kepada fasa 1 dan fasa 2 . Fasa 1 adalah terdiri daripada Sum of Absolute Differences (SAD) iaitu sebahagian daripada padanan blok asas dan Scanline Optimization (SO), sebahagian daripada teknik pengaturcaraan dinamik manakala fasa 2 terdiri daripada proses segmentasi, penggabungan dan penapis median asas. Ciri utama algoritma DSF adalah pada fasa 2 atau sebagai pasca-pemprosesan untuk menghilangkan aspek-aspek yang tidak diingini seperti hingar rawak dan jalur-jalur mendatar yang terhasil daripada peta perbezaan kasar daripada langkah pengoptimuman. Dalam usaha untuk menghapuskan aspek-aspek yang tidak diingini, dua peringkat proses penapisan diperlukan bersama teknik yang direka dalam pasca-pemprosesan algoritma DSF. Terdapat dua kategori penilaian yang dilakukan pada hasil peta perbezaan daripada algoritma-algoritma : penilaian objektif dan penilaian subjektif. Penilaian objektif termasuk sistem penilaian yang ada dalam laman web Middlebury Stereo Visio, analisis komputasi dan kaedah-kaedah tradisional seperti Mean Square Error (MSE), Peak to Signal Noise Ratio (PSNR) dan Similarity Structural Index Metric (SSIM). Selain itu, penilaian subjektif adalah menggunakan dataset yang dirakam daripada kamera LNC IP dan hasil daripada beberapa algoritma yang dipilih dinilai oleh penglihatan manusia. Berdasarkan hasil penilaian, keputusan yang dihasil oleh algoritma DSF adalah lebih baik berbanding algoritma Basic Block Matching dan Dynamic Programming.

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LIST OF ABBREVIATIONS

1D	-	One Dimensional
2D	-	Two Dimensional
3D	-	Three Dimensional
AD	-	Absolute Difference
BM	-	Bidirectional Matching
BBM	-	Basic Block Matching
CUDA	-	Compute Unified Device Architecture
DP	-	Dynamic Programming
DSI	-	Disparity Space Image
DSF	-	Double Stage Filter
GPU	-	Graphic Processing Unit
IP	-	Internet Protocol
LNC	-	Low Noise Converter
MF	-	Matching Function
MSE	-	Mean Squared Error

NCC	-	Normalized Cross Correlation
PSNR	-	Peak Signal to Noise Ratio
RMS	-	Root Mean Squared
SD	-	Squared Difference
SO	-	Scanline Optimization
SAD	-	Sum of Absolute Difference
SNR	-	Signal to Noise Ratio
SSD	-	Sum of Squared Differences
SSIM	-	Structural Similarity Index Metric
WTA	-	Winner Take All

LIST OF SYMBOLS

$\boldsymbol{x}$	-	Pixel in column
$\boldsymbol{y}$	-	Pixel in row
$\boldsymbol{I}$	-	Image
$\boldsymbol{d}$	-	Position increment of a pixel
$\boldsymbol{W}$	-	Square window for aggregation
∇	-	Gradient
w	-	Absolute weighting
$*$	-	Multiply
P	-	Disparity plane
S	-	Segment
λ_{disc}	-	Common border lengths
C_{census}	-	Hamming distance between the correspondence pixels of left image and right image
d_p^*	-	Highest votes or bin value for the disparity
S_p	-	Total number of good pixels

d_p	-	Value of disparity map
E	-	Edges
m	-	Matching penalty
t	-	Threshold
N	-	Neighborhood
y_k	-	Data point upon the iteration
a_x	-	Number of pixels in the segment from data point of x
A	-	Aggregated area
Occ	-	Occluded pixels
σ_i	-	Input of noise variance
$f(\bar{n})$	-	Function of noise density

LIST OF PUBLICATIONS

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CHAPTER 1

INTRODUCTION

1.1 Background

Stereo matching is one of the popular topic in the field of computer vision and gain interest among researchers. Stereo vision is a technique on inferring depth from stereo camera with division of left and right side to form stereo pair images for stereo matching algorithm purpose (Bleyer & Gelautz, 2005). Stereo matching algorithms are the procedure to obtain a disparity depth map from the corresponding pixels from the pair of stereo images. It can be used in 3D reconstruction, scene analysis and other depth related usage. Most computer vision based approaches for extracting stereo information can mainly classified as monocular and dual-camera system. The analysis of depth details which from monocular and dual-camera are through its disparity and depth map (Scharstein & Szeliski, 2002). Disparity and depth map data can be gathered by capturing the stereo image simultaneously and calculated through stereo matching algorithm (Guillemaut & Hilton, 2012). Disparity depth map is used to synthesize the inter-view images based on the depth layer extraction (Bleyer & Gelautz, 2005) .The depth information in a scene for a stereo image is used in many image analysis and 3D video processing applications.

There are many stereo matching algorithms has been developed, which can be found in the Middlebury Stereo Vision Website by (Scharstein & Szeliski, 2002). This particular website provides various datasets of stereo images and standard evaluation for researchers to compare the results obtained from their proposed stereo matching algorithm with other. In general, most stereo matching algorithm consist of four common steps such as matching cost computation, cost aggregation, disparity computation optimization and disparity refinement according to (Scharstein & Szeliski, 2002). However, the four steps are not necessary to be included in a stereo matching algorithm as it is depending on the design developed by the researchers.

In the development of stereo matching algorithm, the most preferable step which attracts the interest from the researchers is on the post-processing step. Post-processing is the step of disparity refinement where the raw disparity map obtained from computation of correspondence and optimization. The raw disparity map contains some noises, mismatches and holes from occlusion, which need to be smoothed out and removed. There are various type of post-processing can performed such as sub-pixel estimation, median filter, cross-checking and surface fitting (Fua, 1993; Heo, Lee, & Lee, 2011; Li & Li, 2008; Ma & He, 2013). Some algorithms with high processing speed may obtain a relatively low precision of disparity depth map (Bobick & Intille, 1999; Calakli, Ulusoy, Restrepo, Taubin, & Mundy, 2012; Zhou, Troccoli, & Pulli, 2012).

1.2 Problem Statement

There are many stereo matching algorithms can be found in the field of image processing. However, some of the stereo matching algorithms lack of accuracy in obtaining the disparity depth map. 3D triangulation and effects on image processing depending on the smoothness of the disparity depth map that obtained from stereo matching algorithms. The smoother the disparity depth map, the better effect of 3D applications (Gong & Yang,