Haar Filter Hardware Architecture for the Accuracy Improvement of Stereo Vision Systems

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Abstract— **In stereo vision systems, mismatching can occur frequently in specific regions containing noise and high-frequency components, such as checkered patterns. Therefore, this paper proposes a preprocessing method and architecture based on a 2-D Haar filter to improve the matching accuracy of disparity map by reducing the high-frequency and noise components. In this paper, the disparity map is computed by the semi-global matching (SGM) method, and separable weighted median filter is adopted as postprocessing. The SGM with proposed method reduces the average number of mismatching pixels by 3.5233% in non-occlusion condition and 3.2647% in occlusion condition compared to that with a 2-D Gaussian filter when using the KITTI 2015 stereo dataset. The proposed method is suitable for embedded stereo vision systems that requires high matching accuracy with reasonable resource overhead.**

Keywords— preprocessing; stereo vision; semi-global matching; 2-D Haar filter

I. INTRODUCTION

As the autonomous driving market has grown rapidly in recent years, several studies on advanced driving assistance system (ADAS) have been actively conducted to provide convenience services to drivers [1,2]. To implement the functions of ADAS, 3-D information, which are collected by cameras, radar, and lidar sensors, are used in various fields such as object recognition and distance information acquisition [3]. Among them, the camera sensor is widely used because it can acquire 3-D distance information and recognize the color of an object. Stereo matching, which is depth sensing technology using camera sensors, is essential for computing the disparity map to acquire and analyze the distance information. In stereo matching methods, the semi-global matching (SGM) method is widely used because of its high matching accuracy and fast processing speed [4]. However, the matching accuracy of the SGM method can be degraded owing to noise and high-frequency components. To overcome these problems, a 2-D Gaussian filter is widely used for preprocessing to reduce the high-frequency and noise components of input images and improve the matching accuracy of the disparity map [5,6]. However, the SGM method, which adopts a 2-D Gaussian filter as preprocessing, has still low matching accuracy of the disparity map in particular regions containing noise and high-frequency components. Therefore, in this paper, we propose a preprocessing method and architecture based on a 2-D Haar filter for the SGM to improve the matching accuracy of disparity map compared to 2-D Gaussian filter.

II. PROPOSED METHOD

The proposed method is based on a 2-D Haar filter as preprocessing for the SGM method to improve the matching accuracy of the disparity map in the noise and high-frequency regions. When using a 2-D Haar filter, four types of detail coefficients are computed, and they are based on the low-low (LL), low-high (LH), high-low (HL), and high-high (HH) frequency sub-bands, respectively. In the proposed method, three types of detail coefficient components, except for LL, are used to reduce the high-frequency and noise components in the original input image. To reduce the high-frequency and noise components, the HH coefficient, which is multiplied by weighting factor, is subtracted from the original input image. To compensate for the pixel value in the edge line, the original input image is calibrated using LH and HL coefficients that are multiplied by weighting factor. After the preprocessing step, the generated image by using the proposed method was entered into the SGM method, which adopts separable weighted median filter (sWMF) [7] as postprocessing, to compute the disparity map, as shown in Fig. 1.

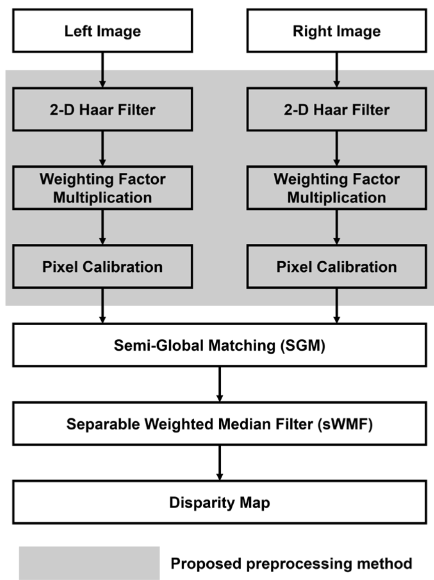

Figure 1. SGM system using the proposed method as preprocessing

III. PROPOSED ARCHITECTURE

Fig. 2 demonstrates the proposed architecture based on a 2-D Haar filter for the SGM method. The proposed architecture consists of the line buffer, coefficients calculator, and weight multiplier and calibration calculator. The line buffer stores the pixel value of input image to generate 2 × 2 sub-window. The pixels of sub-window are entered into the coefficient calculator for computing the three types of detail coefficients. In the weight multiplier and calibration calculator, the three types of detail coefficients are multiplied by weighting factor using shift operation and calibrated from pixel value of the original input image to generate a calibrated pixel. The calibrated pixel is entered into the SGM module to compute the disparity map.

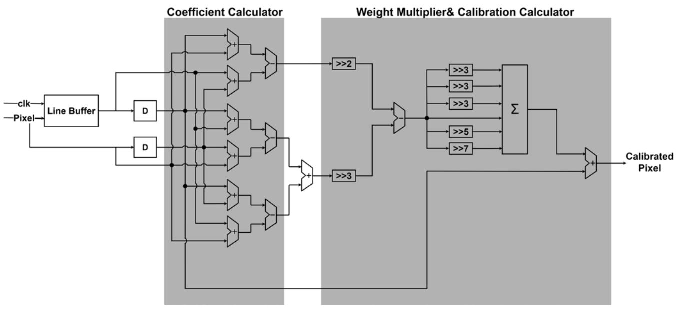

Figure 2. Hardware architecture of the proposed preprocessing method

IV. EXPERIMENTAL RESULT

Table I presents the hardware resource usage of the proposed architecture and a 2-D Gaussian filter when they are implemented on Xilinx FPGA Virtex-7 XC7V2000T-FLG1925-2. In the proposed architecture, the number of slice LUTs and slice registers is slightly higher than a 2-D Gaussian filter. On the other hand, the number of block RAMs (BRAMs) is smaller than a 2-D Gaussian filter.

TABLE I. COMPARISON OF HARDWARE RESOURCE USAGE

Resources	2-D Gaussian filter	Proposed architecture
Slice LUTs	110	137
Slice Registers	180	191
BRAMs	2	1

Table II presents the disparity mean error rate (MER) and the average number of mismatching pixels using our proposed method and a 2-D Gaussian filter as preprocessing for SGM adopting sWMF, respectively. To compare the performance, we used the MATLAB R2020b tool to run the evaluation code provided by KITTI [8]. The mismatching results of non-occlusion and occlusion condition are computed using 200 images from the KITTI 2015 stereo dataset [8]. When using the 128 disparity range and 13 × 13 sub-window size of sWMF, the non-occlusion MER using proposed method is 21.6888% and the average number of mismatching pixels is 101015, which is 3.5233% better than using a 2-D Gaussian filter. The occlusion MER using the proposed method is 23.0561% and the average number of mismatching pixels is 107383, which is 3.2647% better than using a 2-D Gaussian filter.

TABLE II. COMPARISON OF PERFORMANCE BETWEEN THE PROPOSED METHOD AND 2-D GAUSSIAN FILTER

	Non-Occlusion		Occlusion	
	Mismatching pixels	MER (%)	Mismatching pixels	MER (%)
SGM with Gaussian filter	104704	22.4809	111007	23.8341
SGM with proposed method	101015	21.6888	107383	23.0561
Improvement (%)	3.5233	-	3.2647	-

V. CONCLUSION

In this paper, we proposed a preprocessing method and architecture based on a 2-D Haar filter for the SGM to improve the matching accuracy of disparity map. Although the slice LUTs and slice registers of proposed architecture are slightly higher than a 2-D Gaussian filter when implemented on FPGA, the average number of mismatching pixels is reduced under occlusion and non-occlusion conditions. Therefore, it is suitable for embedded stereo vision systems that requires high matching accuracy with reasonable resource overhead.

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