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Advanced Researches on Software Technology

SERSC

SoftTech 2013

Dominik Slezak
Wai-chi Fang
Sabah Mohammed
Young-hoon Lee
Jong-an Park (Eds.)

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A Cost-Effective Local Stereo Matching Based on the Unconventional Window

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Abstract. This paper proposes an efficient stereo matching method using the window with the size of 2^k by 2^k that can be implemented in high-performance stereo matching systems. To evaluate the proposed method, various matching methods are modeled with C and implemented with an HDL. The experimental results show that the proposed method can reduce computational complexity without significant performance reduction compared with the conventional window based method.

Keywords: Stereo matching, Local matching, Depth, Window size.

1 Introduction

The stereo matching is a search problem which finds the accurate correspondence points between the left and right images. If the camera model is given and the correspondence points are found, the depth information can be computed by triangulation [1].

Most visual systems studies based on the stereo matching use the difference-based local matching methods such as SAD (Sum of Absolute Differences) or SSD (Sum of Squared Differences) [2]. This is mainly because of the limitation of the hardware resources and computation complexity. These difference-based matching methods are simple to implement, but have high matching error rate due to the differences in the brightness of the images. Because of the disadvantage of difference-based stereo matching, the correlation-based local matching methods such as Census transform or NCC (Normalized Cross Correlation) have been studied [3]. These methods are robust to matching ambiguity caused by the noise and intensity change. However, the correlation-based local matching methods are time-consuming procedures because of the complexity of the functions. For real-time performance, a lot of studies have been proposed, but these require a number of hardware resources for the parallelism.

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In this paper, we propose an efficient arithmetic based stereo matching method that can reduce the usage of the hardware resources using the unconventional windows and we show that this method can be used to implement the low-cost and high-performance stereo matching system.

2 Stereo Matching with 2^k by 2^k Window

Local matching methods compute each pixel's disparity independently. The matching cost is aggregated over each disparity range, and the disparity level with the minimal cost is selected as the output of the pixel. Local matching methods utilize color or intensity values within a finite window to determine the disparity.

The performance of the local matching methods depends mainly on the window size. Small windows increase the quality at borders and the localizing of matches is more accurate, but they can cause more false matches. In contrast, large windows are proper for accurate correspondence, but the computational overhead is extremely increased. This paper uses unconventional windows in order to overcome this problem. As shown in Fig. 1, the proposed window has the size of 2^k for width in x and y-axis (2^k by 2^k) unlike the conventional window.

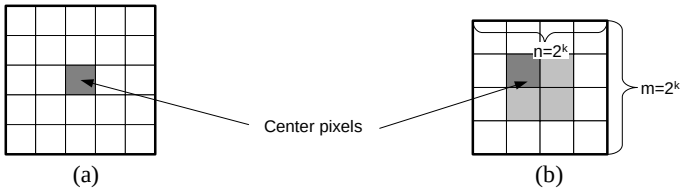


Fig. 1. Local matching windows: (a) conventional window, (b) proposed window.

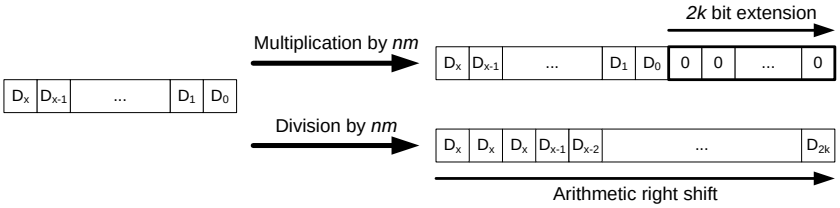


Fig. 2. Multiplication and division replacement by the proposed matching window.

According to the equation of local matching methods, multiplications and divisions by *nm*, the product of the width and height of the matching window, are included during the computing procedures. These operations require high computational overhead. As shown in Fig. 2, when the proposed window is used for stereo matching, the multiplications by *nm* can be replaced with the bit extension with *2k* numbers of zero and the divisions by *nm* is also substituted with arithmetic right shift operations. This enables the proposed method to reduce hardware resources compared with conventional window based method.

3 Experimental Results

To analyze the impact of the proposed window size on the matching results, the local matching methods are modeled with C. For objective performance comparison, matching results are generated with Middlebury benchmark [4].

Table 1 shows the simulation result images and error rates of local matching methods (SAD and NCC) with the proposed and conventional window sizes. As shown in experimental results, the matching error rate is decreased when the window size is increased. However, when using the similar size of windows, the simulation results for the proposed window size are almost the same with those for the conventional window size. This comparison shows that the proposed method with the unconventional windows has little impact on the matching results compared with conventional window based methods.

Table 1. Simulation result images

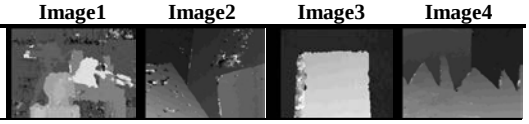
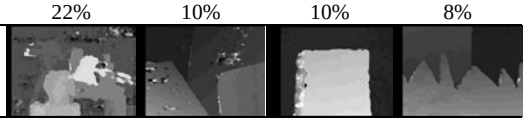
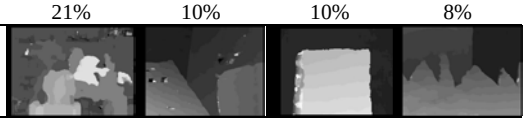
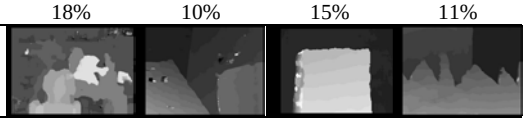
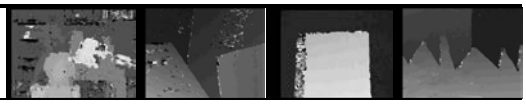
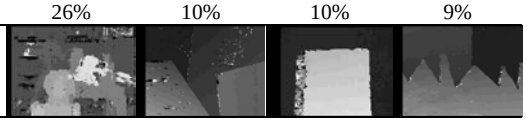
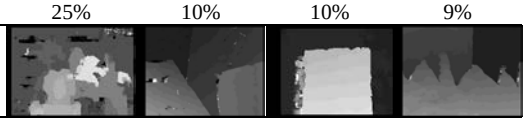
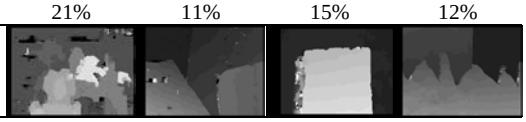
		Image1	**Image2**	**Image3**	**Image4**
SAD	8 by 8 (proposed)				
	error rate	22%	10%	10%	8%
	9 by 9 (conventional)				
	error rate	21%	10%	10%	8%
	15 by 15 (conventional)				
	error rate	18%	10%	15%	11%
	16 by 16 (proposed)				
	error rate	17%	10%	15%	11%
NCC	8 by 8 (proposed)				
	error rate	26%	10%	10%	9%
	9 by 9 (conventional)				
	error rate	25%	10%	10%	9%
	15 by 15 (conventional)				
	error rate	21%	11%	15%	12%
	16 by 16 (proposed)				
	error rate	21%	11%	15%	12%

Table 2. Usage of hardware resources

	16 by 16 (proposed)	15 by 15 (Conventional)
Slice Registers	88,165	105,416
Slice LUTs	71,050	74,320
Fully used LUT-FF pairs	22,304	26,288
DSP 48Es	32	32

Also, for the comparison of the usage of hardware resources between the conventional window based matching and the proposed window based matching, an NCC matching circuit with the proposed unconventional matching window size and one with the conventional window size were designed using Verilog HDL and implemented in Xilinx Virtex5 LX330 FPGA. 15 by 15 and 16 by 16 are used as the conventional and unconventional window sizes, respectively. As shown in Table 2, the usage of hardware resources of the circuit with the unconventional window size of 16 by 16 is much smaller than that of the circuit with the conventional window size of 15 by 15, even though the one has the larger window than the other.

4 Conclusion

Stereo matching methods require large windows for low matching error rate, which they result in high computational complexity. Many multiplications and divisions by the product of the width and height of the matching window are the main factors to increase computational complexity in the conventional window based matching method. This paper proposes the method that uses windows of the size of 2^k by 2^k to implement stereo matching having large windows with low complexity by removing multiplications and divisions by the width and height of the matching window. The experimental results show that the proposed window method can reduce hardware resources without performance reduction compared with the conventional window based method.

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