

A Fast Integral Image Computing Methods: A Review

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ABSTRACT

Integral image computing is an important part of many vision applications and is characterized by concentrated computation and frequent memory accessing. This brief proposes an approach for fast integral image computing with high area and power efficiency for vision applications in embedded systems. For the data flow of the integral image computation a dual-direction data-oriented integral image computing mechanism is proposed to improve the processing efficiency, and then a pipelined parallel architecture is designed to support this mechanism. The parallelism and time complexity of the approach are analysed and the hardware implementation cost of the proposed architecture is also presented. Compared with the state-of-the-art methods this architecture achieves the highest processing speed with comparatively low logic resources and power consumption. And according to review we can improve the high area and power efficiency.

Keywords - Integral Image, Parallel Processing, Pipelined Architecture.

I. INTRODUCTION

Integral image computing is a very important and convenient method to accelerate the feature computation in the vision algorithms. The Integral Image or Summed Area Table, was first introduced to us in 1984, but wasn't properly introduced to the world of Computer Vision till 2001 by Viola and Jones with the Framework. The Integral Image is used as a quick and effective way of calculating the sum of values (pixel values) in a given image – or a rectangular subset of a grid (the given image). It can also, or is mainly, used for calculating the average intensity within a given image. If one wants to use the Integral Image, it is normally a wise idea to make sure the image is in greyscale first.

It can be used to compute the Haar-like feature in the Adaptive Boosting (AdaBoost)-based face detection [1], [2], speech detection, and human activity recognition [3], and can also be used to compute the Speeded Up Robust Features in the corresponding detection occasions [4]. Although the integral image is an effective way to quickly compute the features, the computing of integral image is computation and memory accessing intensive, and usually accounts for large parts of the total execution time. In embedded vision applications such as object detection in automotive systems, biomedical systems, and some portable systems, real-time processing is required within a limited power budget and hardware implementation size. Since specialized hardware consumes less power and can be built into small systems, it is more suitable for embedded applications. Thus, the implementation of fast integral image computing on specialized hardware is of vital practical significance. Some different approaches have been proposed in related works to improve integral image computing

efficiency, such as the Kyrkou's and Hiromoto's methods [5] and [6]. However, the existing approaches have some drawbacks since the parallelism of the integral image computing is not fully exploited during computation. A faster speed of computation could be achieved with comparatively low power and in a small area by fully exploiting the parallelism in the computation. In this brief, we propose a dual-direction data-oriented integral image computing method to exploit the parallelism, and we design a parallel hardware architecture based on the proposed method.

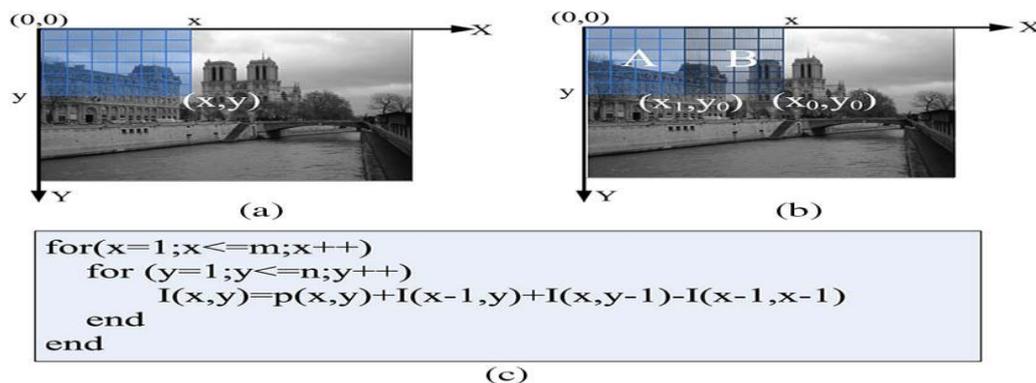


Fig. 1. Integral image computation. (a) Integral image definition. (b) A property of integral image. (c) Pseudo-code of integral image computing code.

To evaluate the proposed architecture, we implement the integral image computing methods in [5] and [6] on hardware for comparison. The performance metrics, including speed, area, and power, are evaluated to show the efficiency of the architecture.

II. INTEGRAL IMAGE COMPUTATION

Integral image, which is known as the summed area table, is a data structure that can quickly and efficiently compute the sum of values in a rectangular subset of a grid [7]. The integral image value $I(x, y)$ at location (x, y) , which is defined in following, is equal to the sum of the intensity of all pixels above and to the left of location (x, y) in the original image $p(x, y)$, as shown in Fig. 1(a):

$$I(x, y) = \sum_{x' \leq x} \sum_{y' \leq y} p(x', y'). \quad (1)$$

Given an $m \times n$ image, the integral image value $I(x, y)$ can be computed according to the pseudocode shown in Fig. 1(c), where $I(x, y)$ depends on $I(x - 1, y)$, $I(x, y - 1)$, and $I(x - 1, y - 1)$. The integral image has a property that we can make use of in hardware design [see Fig. 1(b)]. The integral image value at (x_0, y_0) is the sum of the intensity of all the pixels in area A plus the sum of intensity of pixels in area B, which is shown in (2). Since the first term on the right part of (2) is the value of the integral image at the point (x_1, y_0) , we can obtain (3) in

$$I(x_0, y_0) = \sum_{x' \leq x_1} \sum_{y' \leq y_0} p(x', y') + \sum_{x_1 \leq x' \leq x_0} \sum_{y' \leq y_0} p(x', y') \quad (2)$$

$$I(x_0, y_0) = I(x_1, y_0) + \sum_{x_1 \leq x' \leq x_0} \sum_{y' \leq y_0} p(x', y'). \quad (3)$$

Hence, when the integral image of A is computed, if we want to compute the integral image values in B, we can regard B as an independent image and compute its integral image; then, we add each row of integral values with the rightmost value at the same row in the integral image of A. Therefore, we only need to know the value of the rightmost column in the integral image of A to compute the integral image value of B.

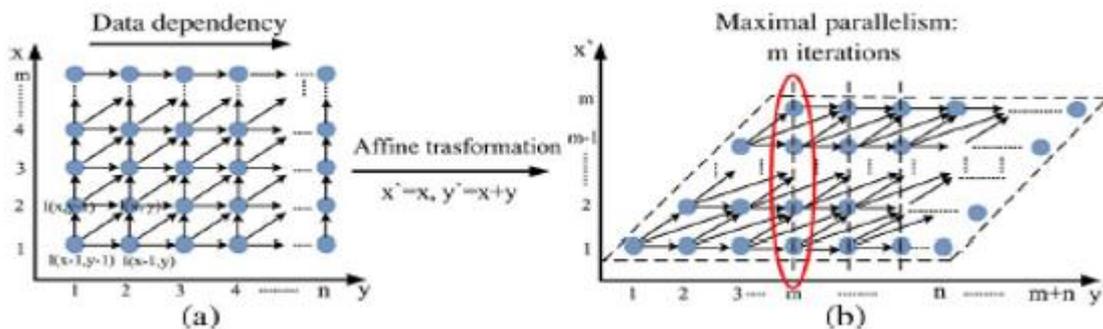


Fig. 2. Affine transformation of nested loop for integral image computing (a) Dependency graph of original loop. (b) Dependency graph of transformed loop.

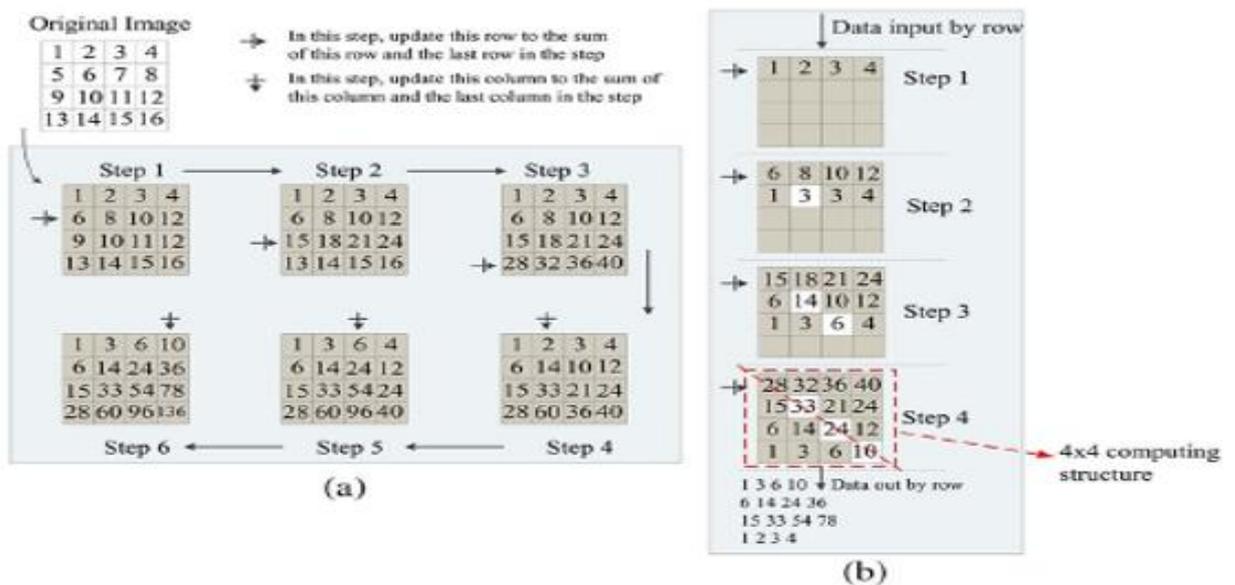


Fig. 3. Proposed computing method to exploit the parallelism. (a) Proposed method. (b) Pipeline processing.

III. PENG OUYANG PROPOSED METHOD

In order to exploit the parallelism for hardware design, we need to analyse the data dependence of integral image computing. The loop dependence graph of Fig. 1(c) is shown in Fig. 2(a). Each iteration $I(x, y) = p(x, y) + I(x - 1, y) + I(x, y - 1) - I(x - 1, y - 1)$ is represented by one small circle, and it depends on the prior iterations. For example, the iteration $I(x, y)$ depends on the iterations $I(x, y - 1)$, $I(x - 1, y - 1)$, and $I(x - 1, y)$. To achieve the maximal parallelism, we use affine loop transformation to transform the original loop to a new form, which is shown in Fig. 2(b), and we can find that the maximal parallelism is m as the iterations in the red circle have no dependence between each other and can be processed in parallel.

Hence, we propose a dual-direction (row direction and column direction) data-oriented method to exploit this parallelism. As shown in Fig. 3(a), we use a 4×4 image to illustrate

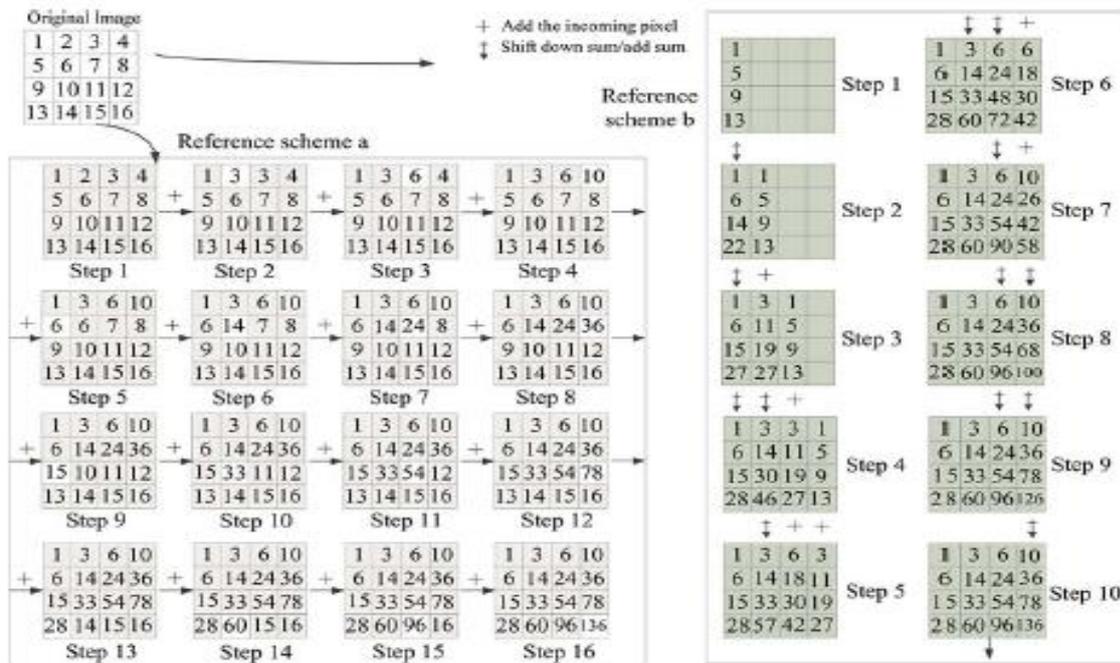


Fig. 4. Two reference integral computing schemes.

this method. Only six steps are used to compute the integral image. According to this method, for an $m \times n$ image, we need $n - 1$ row operations and $m - 1$ column operations to compute its integral image; thus, $m + n - 2$ steps in total are needed, and the time complexity is $O(m + n)$, which is much lower than the time complexity of the conventional full accumulation algorithm ($O(mn)$). In Fig. 4, we adopt two related methods for comparison. The reference scheme a denote Hiromoto's integral image computing method in [6], and the reference scheme b denotes Kyrkou's integral image computing method in [5]. Hiromoto's method is similar with the full accumulation algorithm and needs 16 steps with time complexity of $O(mn)$. In Kyrkou's method, the operations include adding the incoming pixels into the stored sum, propagating the incoming pixel to the next column, and shifting and adding the stored value in the vertical dimensions. It needs ten steps with time

complexity of $O(2m + n)$. Our method shows the obvious advantage over these two methods. Further, to fully exploit the parallelism, a pipelined structure can be designed as shown in Fig. 3(b), where the image is accessed row by row, reducing further time complexity to $O(n)$. This reduction is done by adding the incoming row of pixels to update the current row of pixels in each cycle, and column operations can be achieved using cascaded row registers and adders between them. By means of pipeline processing, the parallelism of m shown in Fig. 2(b) can be achieved by an $m \times m$ processing structure. For example, as shown in Fig. 3(b), four integral image data in the diagonal region are computed in parallel by a 4×4 computing structure. The detailed hardware architecture based on this design concept is illustrated in Section IV. For images of large size, we could not access a whole row simultaneously as the output data width of memory that stores image pixels is limited. To solve this problem, we divide the image into several “strips.” As shown in Fig. 5(a), we first compute the integral image of strip 1 and store the rightmost integral value of each row of strip 1. Then, we use the property mentioned in Section II to compute the integral image values in strip 2. Similarly, we store the rightmost integral value of each row of strip 2 and compute the integral image values in strip 3. We repeat the same operations for the rest strips. These strips are computed in a pipeline way, as shown in Fig. 5(b). For an $m \times n$ image, if the width of each strip is w (Usually m could be exactly divided by w), it will take n steps to compute each strip, and there would be m/w strips. In addition, each strip is computed using a pipelined structure with cascaded row

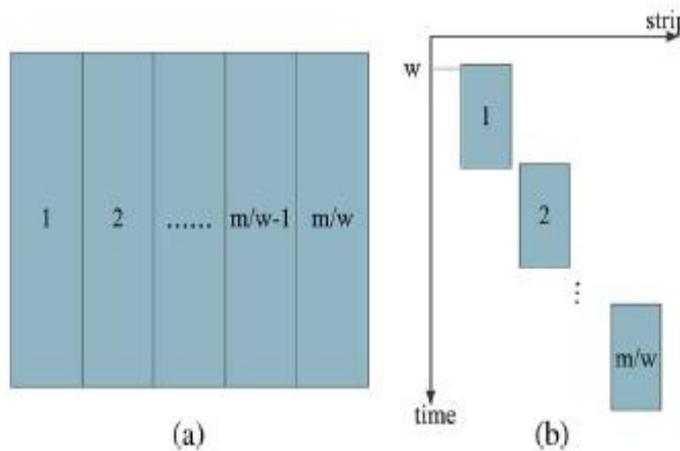


Fig. 5. ‘Strips’ mechanism for large image. (a) Image is divided in to strips. (b) Strips are processes in pipeline way.

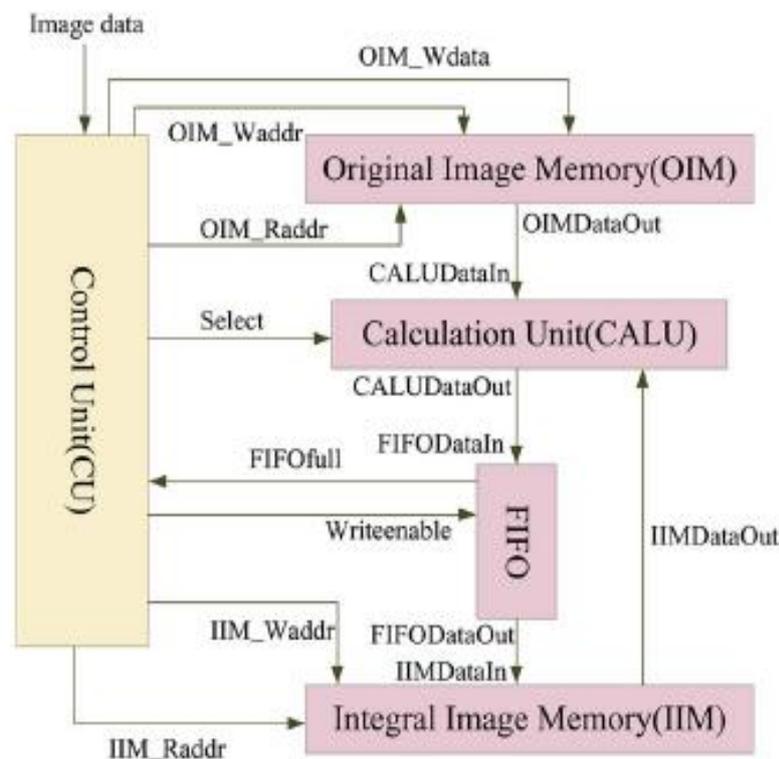


Fig. 6. System Overview

and column operations, which causes a delay of w steps in the cascaded structure to fill the pipeline. Thus, in total, it will take

S_{num} steps to compute the integral image. S_{num} is defined as

$$S_{num} = w + m/w \times n. \quad (4)$$

By selecting an appropriate value of w , we can achieve the highest efficiency by trading off between speed, area, and power dissipation.

IV. VERIFICATION

In this section, the proposed architecture is implemented on a field-programmable gate array (FPGA), and the functionality and system performance are evaluated. Details of our experiment are shown in the following.

A. Experiments Set Up

We adopt 3000 sample images to evaluate the average performance of this brief. These images are in multiple sizes (640×480 , 1280×720 , 1920×1080 , and 4096×2160) used in our experiment. According to review, we have a comparison between Kyrkou, Hiromoto and Peng Ouyang. The testing results are shown below.



TABLE I
FUNCTIONALITY VERIFICATION

Data set	Performance metric	Kyrkou [5]	Hiromoto [6]	Baseline scheme	This work
CMU	DR	93.0%	93.0%	93.0%	93.0%
	FPR	0.00054	0.00054	0.00054	0.00054
Yale	DR	94.1%	94.1%	94.1%	94.1%
	FPR	0.00061	0.00061	0.00061	0.00061
ORL	DR	94.8%	94.8%	94.8%	94.8%
	FPR	0.00079	0.00079	0.00079	0.00079

TABLE II
COMPUTATION SPEED

Image size	Kyrkou[5]	Hiromoto[6]	This work
640×480	1339 fps	163 fps	5191 fps
1280×720	446 fps	54 fps	1734 fps
1920×1080	198 fps	24 fps	771 fps
4096×2160	46 fps	6 fps	181 fps

TABLE III
HARDWARE RESOURCES

	Kyrkou[5]	Hiromoto[6]	This work
Computation Unit#(LEs)	2682	1316	2537
Control Unit#(LEs)	542	213	921
Total #(LEs)	3224	1529	3458

When testing on the same set of images, the average detection rate (DR) and false positive rate (FPR) are the same, which means that the integral images computed by different schemes are the same. These results prove that our architecture achieves the correct integral image data. For different sets of images, DR and FPR are different due to the different image contents in different image sets.

C. System Performance

The comparison results of processing speed on different sizes of images are listed in Table II. The area (number of LEs) of integral computing unit and CU are shown in Table III. In experiments, the memory including the input memory for original images and output memory for integral images are the same for Kyrkou’s method [5], Hiromoto’s method [6], and this brief. In addition, we present the synthesis power results of different sizes of images in Table IV. In this brief, for an $m \times n$ image, the time complexity is $O(n)$, whereas it is $O(2m + n)$ in Kyrkou’s method and $O(mn)$ in Hiromoto’s method.

Meanwhile, the pipeline manner of cascade accumulation by row greatly improves the processing efficient. As shown in Table II, this brief achieves the highest speed for images with different sizes. Since we design the strip-based unique memory architecture in the CU and exploit high parallelism for the computing unit, the

power and hardware cost per operation in integral image computing are largely reduced, although the total power and area cost are slightly higher than Kyrkou’s method and Hiromoto’s method as shown in Tables III and IV. The power efficiency (i.e., computation speed per unit power) and area efficiency (i.e., computation speed per unit area) is related to processing speed, power, and hardware resource. By choosing $w = 32$ in the CALU design, the power efficiency and area efficiency are also improved. This is because that our

**TABLE IV
POWER CONSUMPTION**

Image size	Kyrkou[5]	Hiromoto[6]	This work
640×480	8.82 mW	2.53 mW	9.01 mW
1280×720	21.93 mW	8.13 mW	22.52 mW
1920×1080	47.62 mW	19.20 mW	54.6 mW
4096×2160	220.5 mW	96.1 mW	231.7 mW

**TABLE V
SPEED PER UNIT AREA**

Image size	Kyrkou[5]	Hiromoto[6]	This work
640×480	0.415 fps/LE	0.107 fps/LE	1.501 fps/LE
1280×720	0.138 fps/LE	0.035 fps/LE	0.501 fps/LE
1920×1080	0.061 fps/LE	0.016 fps/LE	0.223 fps/LE
4096×2160	0.014 fps/LE	0.0039 fps/LE	0.052 fps/LE

**TABLE VI
SPEED PER UNIT POWER**

Image size	Kyrkou[5]	Hiromoto[6]	This work
640×480	151.8 fps/mW	64.4 fps/mW	576.1 fps/mW
1280×720	20.3 fps/mW	6.6 fps/mW	77.0 fps/mW
1920×1080	4.15 fps/mW	1.25 fps/mW	14.12 fps/mW
4096×2160	0.21 fps/mW	0.06 fps/mW	0.78 fps/mW

parallel architecture improves the data reuse and reduces the memory access cost per operation, resulting in high power and area efficiency. As shown in Tables V and VI, our speed per unit area is 3.61 ~3.66 times higher than Kyrkou’s and 13.3 ~ 14.2 times larger than Hiromoto’s; our speed per unit power is 3.74 ~3.79 times higher than Kyrkou’s and 8.9 ~12.5 times higher than Hiromoto’s.

V. CONCLUSION

In this brief, According to Peng Ouyang, Shouyi Yin, Yuchi Zhang, Leibo Liu, and Shaojun Wei proposed a fast integral image computing method and construct the parallel and pipelined architecture. Compared with state-of-the-art methods, the proposed architecture achieves fast computation speed with higher power and area efficiency. According to review we can improve a fast integral image computing method and construct the parallel and pipelined architecture with high area and power efficiency. This architecture can be used in embedded systems for many vision based applications that depends on integral image computing.

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