A Hardware System of Fast Optical Flow Detection by the Gradient Method

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1 Introduction

In recent years, remarkable development in computer technology hasmade analysis processing of image sequence possible. Onward, advancement of technologies such as image capturing devices and movement sensors have made image sequence can be captured in high resolution. Such image sequence demands real-time processing. For instance, detecting moving object and recognizing object position in 3D space from image sequences used in robot vision system. Such system requires image sequences to be processed quickly and accurately. In image processing, the use of high frame rate image sequence is effective for tracing object movement, considering small movement that can be captured on consecutive frames.

Optical flow estimation method calculates movement vector of each pixel for analyzing object movement in consecutive image sequence. Using such method, relative speed vectors from the whole image sequences can be obtained. Such information can provide detailed information of object movement. The application of this method is object movement detection, motion based region division, and 3D motion analysis. However, high complexity of optical flow calculation prevents real-time processing. Therefore, hardware implementation of optical flow estimation system is required. Hardware implementation is expected to give real-time calculation of optical flow estimation. Beside real-time calculation, hardware accelerated optical flow estimation is also expected to process high density flows to enable accurate detection of small movement and fast moving object.

Several exclusive applications of hardware accelerated optical flows estimation have been proposed. For example, the hardware accelerated matching method has been developed to perform matching task by limiting the search range using one-dimensional array consists of 256 processing elements. However, this method perform template matching for block partition which cannot accurately recognize object scaling and rotation. Other hardware using pipeline image processor is proposed to implement spatial local optimization. Such hardware can calculate highly reliable flow vectors rapidly. On the other hand, it required 47.8 ms to process 252×316 pixels of image. Considering this fact, such hardware cannot be used to process high-resolution images in real-time.

In this research, we proposed the methods of calculating Spatial Local Optimization in real-time, and designed implementation of the proposed method on hardware. Generally speaking, our proposed method calculates of weighted columnar summation in local area using spatial local optimization. From observation results, we show that optical flow calculation can be processed in pipeline. Based on these facts, we design the hardware circuit based on the proposed method, and verify the effectiveness of our hardware implementaion.

2 Optical Flow Estimation

The speed detection in image sequences has been researched since early 1970. Many of these researches adopt the method which uses contrast pattern obtained from image sequences for calculating velocity field. The velocity field detected from the image sequence is called optical flow. The method for estimating optical flow is divided into Block Matching Method and Gradient Method.

Matching Method is performed by matching consecutive pattern which will result some displacement vectors. The optical flow is estimated from these displacement vectors.

Different from Matching Method, Gradient Method is a technique of calculating flow vector based on the function known as restraint condition. Such function is relating velocity of optical flow on a certain coordinates to spatial gradient and time gradient at the intensity pattern in image sequence. For assumption the image function is kept invariable when moving. And Gradient Method is divided 2 types based on additional restraint condtion. Spatial Global Optimization Method has the condition of minimizing a spatial change in optical flow, while Spatial Local Optimization Method is assuming that optical flow is constant in the local area for intensity pattern of the same object.

Previous research has proven that Spatial Local Optimization Method can calculate the flow vector with the highest accuracy. Based on this proof, we choose to speed up Spatial Local Optimization Method.

3 Column's Summation Recycling Method

To calculate optical flow based on Spatial Local Optimization Method, an arbitrary-sized local area must be defined. The center of this local area will become the origin of optical flow vector. Based on this local area, all partial differentials of x, y, and t will be calculated and multiplied accordingly. The obtained values is assigned as weight based on coordinate, relative to local area. These values will be summed to obtain weighted local summation. 5 kinds of weighted local summation are made from each local area. For optical flow calculation, these values will be substituted to equation of Spatial Local Optimization Method.

In this calculation, the longest calculation time is weighted local summation for all pixels in the image. To speed up this processing, a method called Reusable Column's Summation Method is used. By utilizing such method, the computational complexity is greatly reduced by reusing a part of the result for an overlapping local area.

In Reusable Column's Summation Method, the weight value that is a 2-dimensional Gauss function can be solved using 1-dimensional Gauss function. As the weights can be calculated separately by columns and rows, the weighted local summation is divided to weighted column's summations for a number of columns. Therefore, a part of weighted column's summations can be shared between overlapping local areas as long as the calculation does not change row. In the other words, a weighted local summation can be calculated by only calculating weighted column's summation as long as local areas are only displaced in x axis.

By using this proposal method, the execution time is reduced to 1/3 compared to processes that repeatedly calculates the weighted local summation. Moreover, the occurrence of image data reading operation decreases by reusing the calculation result. Therefore, the amount of the data transfer decreases and speeds up in transfer rate can be obtained.

4 A Hardware System of Fast Optical Flows Estimation

We designed a hardware to calculate optical flows based on Reusable Column's Summation Method. Column data will be assigned to the hardware at once. Each column data consist of 4 intensity values calculated from partial difference of x, y, t. Each block operates in pipeline fashion. Finally flow vector output of each pixel can be obtained every 5 steps.

It took $(25 + 5 \times x) \times y + 21$ steps for the proposed hardware to process $x \times y$ pixels of image. In experiment with 252×316 pixels of image, the proposed hardware required 4 hundred thousand steps to accomplish the process. If processing clock runs at 33 MHz, then the estimated completion time is 12.3 ms. Pipeline image processor took about 47.8 ms to process image with the same size. Even if the overhead of data input is considered, our designed hardware is still fast enough to process image. To implement such hardware, 276 hundred thousand gates are required.

5 Conclusion

In this paper, we proposed method of calculate Spatial Local Optimization Method using column's summation. Using such method, optical flows are calculated. We designed a hardware circuit based on the proposed methods and show that it enables high speed in pipeline processing. By analyzing of calculation time, we confirm that the proposed hardware operates faster than the conventional system.