コンピュータビジョン 80－10
(1992. 11. 19)

勾配法を使った 高速線パターンマッチングアルゴリズム

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あらまし 勾配法を用いた高速な線パターンマッチングアルゴリズムについて報告する。勾配法は濃淡画像の処理、特にオプチカルフローの抽出に用いられてきた。線パターンに勾配法を適用する一手法として、線パターンの近傍も仮想的な濃度値を持つと仮定する方法が挙げられる。仮想濃度を定めることにより、線パターンが２値であっても濃淡画像として勾配値の演算が可能となる。そこで、容易な条件式を得るため、線パターン近傍に画素濃度の勾配値が線形となるように画素値を定めることで、繰り返し演算の必要を無くし、２枚の２値画像間の線パターンマッチング演算時間を減少させた。本論文では、上記手法によるアルゴリズムを提案し、実験結果を示す。

和文キーワード ラインパターン、パターンマッチング、勾配法、オプティカルフロー制約式、仮想濃度

Fast Line Pattern Matching Algorithm Using Gradient Method

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Abstract We report a fast line pattern matching algorithm using a gradient method in two images. The gradient method has developed in shading image schemes especially extracting optical flow. One way to apply the gradient method in line patterns is to make an assumption that neighbors of line patterns have shading values. Using this assumption, line pattern images can be treated as shading images in spite of original line pattern images being binary. And we can assume arbitrary shading values around the line patterns so that gradients of these shading values are liner and the constraint lines are easily obtained. In this paper we propose the algorithm which reduces calculation time concerning line pattern matching between two binary images and show the experimental results.

英文 key words Line pattern, Pattern matching, Gradient method, Optical flow constraint, Virtual intensity

1.Introduction

It is an important research field in computer vision to analyze 2 dimensional rigid motion from multiple shading images. Shading images are usually translated to line pattern binary images which express features of the objects so that kernel information such as disparity in stereo or optical flow in time varying images are easily obtained. To detect disparities in stereo line pattern images[1] or optical flow in dynamic line pattern images[2] at video rate, faster line pattern matching algorithms are required. It is of course that faster hard ware solves these issues, but faster algorithms effect total computational cost and efficiency.

It is thought that typical matching algorithms to find corresponding pixels are a correlation method[3] and a gradient method[4]. Though both of them are directly applied to shading images, the gradient method can not be applied to binary images because gradient depends on derivatives of shading values. The gradient method is thought to be superior to the correlation method for avoiding corresponding problem. Line pattern matching algorithms need additional methods such as relaxation techniques[5] or labeling techniques[6]. Adopting the gradient method to binary images has possibilities to make matching algorithms need no additional method and calculation time be reduced.

One approach to apply the gradient method to line patterns is to make an assumption that neighbors of line patterns have shading values. Using this assumption, line pattern images can be treated as shading images in spite of original line pattern images being binary. And we can assume arbitrary shading values around the line patterns so that gradients of these shading values are liner. Liner gradients give less calculation step because x and y directional gradients are obtained from tangent lines of the line patterns. Hence we can easily get the well known optical flow constraint equation between corresponding pixels in two images. This optical flow constraint equation is the line on the flow field and this line can be regarded as matching constraint because two pixels on the line patterns are correspond only on the line. So we refer this constraint as the matching line and solutions on the line as matching components.

In this paper we describe how to apply the gradient method to line pattern binary images and propose the fast line pattern matching algorithm using the matching line to solve matching components. In application of this algorithm we show how this algorithm effects in scene analysis for the autonomous land vehicle.

2.The gradient method

2.1.The basic theorem

The gradient method has been developed to extract optical flow. Extracting of optical flow at the pixel level can be computed from an image sequence by making some assumptions about the spatio-temporal variations of image brightness. This computation is implemented using an optical flow constraint which assumes that intensity values of projection of the same point in environment will be similar between time varying images. Let the intensity at location (x,y) of the image at time t be I(x,y,t). The relation of intensities between two time varying images can be described as

$$I(x,y,t) = I(x+\triangle x,y+\triangle y,t+\triangle t). \qquad (1)$$

In the gradient method by assuming I(x,y,t) is differentiable with respect x,y and t and $\triangle x,\triangle y$ and $\triangle t$ are significantly small. We can expand the right-hand of the equation above in first order terms of a Taylor series and obtain

$$I_x \cdot u + I_y \cdot v + I_t = 0 \qquad (2)$$

where I_x,I_y and I_t denote the partial derivatives of intensity with respect to x,y and t respectively, and u=dx/dt and v=dy/dt denote the x directional and y directional components of 2 dimensional optical flow vector.

It is not possible to recover optical flow locally because of the well-known aperture problem[7]. That is, normal component parallel to gradient direction can be determined but tangential component perpendicular to gradient direction remained unsolved. Therefore additional information is required. Horn & Schunk imposed a global smoothness constraint on the optical flow[8]. They introduced the smoothness constraint which assumes that the flow vectors vary smoothly within a small spatial neighborhood region. And they proposed an iterative technique for computing optical flow and solved optical flow constraint equation for optical flow components by minimizing an error functional stated in terms of accuracy and smoothness. Their problems are that it costs much computational time.

Other different techniques for computing pixel level optical flow which avoid iterative calculation include a multi constraints technique. Pixels on the contour of the object give many explicit kinds of constraint equations.

2.2.Multi constraint technique

This idea is to use the intensity values recorded multifiltered images of moving objects obtained using different spatial filters[9] or the intensity values along the contour of the object.[10] Each filtered image is assumed to satisfy the standard optical flow constraint equation at same pixels or each pixels on the contour of the object. Using these simultaneous constraint equations we can solve optical flow components directly. This method imposes no smoothness condition on optical flow and computational time is much shorter than the iterative technique though the use of contour limits parallel translation.

We can acquire another kind of constraint equation

$$I_{1x} \cdot u + I_{1y} \cdot v + I_{1t} = 0 \quad (3)$$

which is obtained from the image $E(x,y,t) * F_1(x,y)$ where $F_1(x,y)$ is a spatial filter and $*$ denotes convolve operation. Using another cut off frequency spatial filter $F_2(x,y)$, the following equation is obtained.

$$I_{2x} \cdot u + I_{2y} \cdot v + I_{2t} = 0 \quad (4)$$

Then u and v can be solved using the simultaneous equation to the next form.

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} I_{1x} & I_{1y} \\ I_{2x} & I_{2y} \end{bmatrix}^{-1} \begin{bmatrix} -I_{1t} \\ -I_{2t} \end{bmatrix} \quad (5)$$

Additional equation will give more accurate calculation results and this simultaneous equation can be written as the next matrix equation

$$\mathbf{Ax} = \mathbf{b} \quad (6)$$

where $x=[u,v]^T$,$b=[-I1t,-I2t, \cdot \cdot \cdot ,-Int]^T$ and

$$A = \begin{bmatrix} I_{1x}, & I_{2x}, \cdot \cdot \cdot ,I_{nx} \\ I_{1y}, & I_{2y}, \cdot \cdot \cdot ,I_{ny} \end{bmatrix}^T$$

In principle, there are many ways in which one could solve the equation (6) for **x**. The standard least squares solution of **x** is given by the next form.

$$\hat{\mathbf{x}} = (\mathbf{A}^T \mathbf{A})^{-1} \mathbf{A}^T \mathbf{b} \quad (7)$$

The solution is same form provided that the rank of **A** is 2.

3.Applying the gradient method to line patterns

3.1.The basic idea

In general, line patterns are reproduced from shading images by simple threshold binarize technique or finding zero crossings. Here we restrict that line patterns are represented the shapes of the rigid object and in a short time measurement line patterns do not change their shapes but positions. The amount of translation is not so large. And we also assume that the width of lines is one pixel.

It is difficult to estimate original shading values, which are obtained from the original shading image, only from line patterns. Therefore the gradient method cannot be applied to line patterns. Nevertheless, we can apply the gradient method by assuming arbitrary virtual shading values around the line patterns. Figure 1 shows this assumption. Suppose the pixel (x,y,t) and $(x,y,t+\triangle t)$ on the line pattern at time t and $t+\triangle t$ have shading values $V(x,y,t)$ and $V(x,y,t+\triangle t)$ which are differentiable and satisfy the optical flow criteria, the following equation can be obtained.

$$V_x \cdot u + V_y \cdot v + V_t = 0 \quad (8)$$

Since virtual shading values may have liner gradient and gradient direction may be decided by such a simple algorithm as assuming that the gradient direction corresponds to the outside direction from the closed line pattern region, V_x and V_y are easily decided. We can determine V_x and V_y more easily by assuming that the steepest gradient direction is perpendicuiar to the tangent of the line. That is,

$$V_x = C \cdot \sin\theta,\ V_y = C \cdot \cos\theta \quad (9)$$

where C is the steepest gradient value and θ is the angle between the x axis and the tangent line.And V_t is determined by calculating a distance between the pixel (x,y,t) and the nearest pixel at time $t+\triangle t$. V_t can be estimated by use of the following equation.

$$V_t = d \cdot C \cdot \cos\varphi \quad (10)$$

where d is the nearest distance between the pixel (x,y,t) and the pixel on the line at time $t+\triangle t$ and φ is the angle between the nearest direction and the normal of the tangent line on the nearest pixel at time $t+\triangle t$ (See figure 2). Using these equation V_x, V_y and V_t are estimated only by assuming the steepest gradient C. Pixels on the line pattern would give the simultaneous equation in case of parallel translation and u and v can be estimated by use of the equation (7).

3.2.Computational details

We can apply the gradient method to the line pattern matching using the basic idea mentioned above. By classifying line patterns to simple one and complicated one, more efficient algorithms can be developed. In this paper line pattern complexity are defined that simple one is constructed only one closed form and complicated one is the other as shown in figure 3.

3.2.1.For simple line patterns

Calculating tangent angles is important to estimate V_x and V_y, and it is easy to obtain tangent angles in simple line patterns. We can estimate the tangent angle by extracting chain codes of the line. The chain codes are constructed eight kinds of number as shown in figure 4 and each number is correspond to each $\pi/4$ step angle. Averaging some neighbor chain codes, tangent angles are obtained as shown in figure 5. That is,

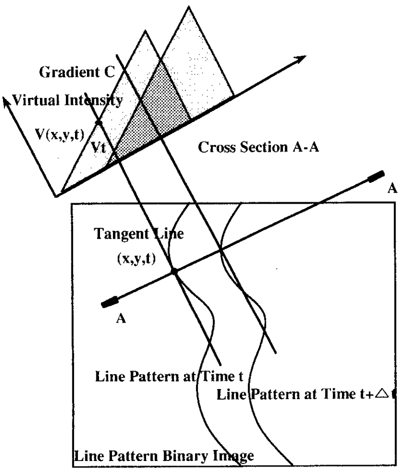
$$\theta = (1/N_p) \cdot \Sigma\ ((\pi/4) \cdot F_i) \qquad (11)$$

where N_p is the number of chain code and F_i $(i=1,2,\cdot\cdot\cdot N_p)$ is the chain code.

3.2.2.For complicated line patterns

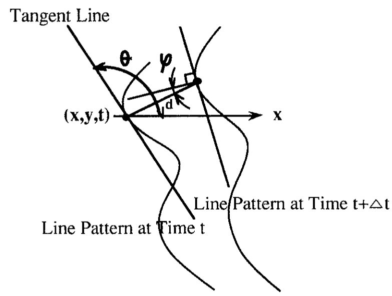
In complicated line patterns V_x, V_y and V_t are estimated by reproducing shading values actually. Using simple average filter, Intensity values around line patterns are obtained and intensity derivatives are calculated directly. These values are calculated by use of the following equations.

$$V_x = (V(x+\triangle x,y,t) - V(x,y,t)) \,/\, \triangle x$$
$$V_y = (V(x,y+\triangle y,t) - V(x,y,t)) \,/\, \triangle y$$
$$|V_t| = |V(x,y,t) - V(x,y,t+\triangle t)| \qquad (12)$$

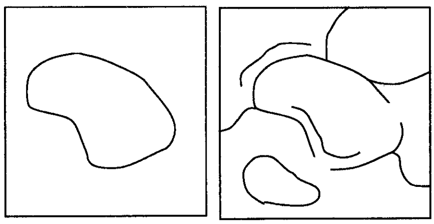


(Figure 1)The basic idea of virtual intensity

Though the simple average filter can be thought not to give accurate liner gradients, these gradients are approximately liner. Coefficients of $|V_t|$ are determined by evaluating the coefficient of the steepest gradient at time $t+\triangle t$. That is, the same coefficient of the steepest gradient at time t as the one at time $t+\triangle t$ gives the positive coefficient of V_t and the different one the negative one. Since these intensity values contain no random noise, these derivatives are obtained by use of these simple equations. In this case also constraint equations on the original line pattern give simultaneous equations concerning u and v.

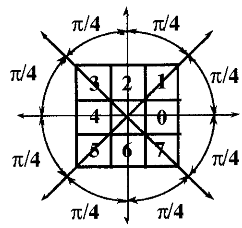


(Figure 2)Tangent line of the line patterns

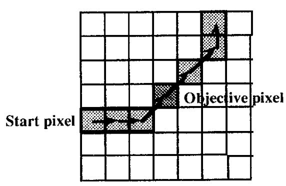


(a) Simple line pattern (b) Complicated line pattern

(Figure 3) Complexity of line patterns



(Figure 4) Chain code and tangent angle



$$\theta = \frac{1}{6}\left(\frac{\pi}{4}\times 0+\frac{\pi}{4}\times 0+\frac{\pi}{4}\times 1+\frac{\pi}{4}\times 1+\frac{\pi}{4}\times 1+\frac{\pi}{4}\times 2\right)$$

(Figure5)Relation between code and tangent

4.Experimental results

4.1.Simple line pattern matching

In this experiment we used the line pattern image of the object obtained by simple binarize technique from the shading image. Figure 6(a),6(b) and 6(c) show the simple line pattern and and its translation and figure 6 (d) 6(e) and 6(f) are extracted optical flow using our algorithm in case of simple patterns when the object is moved. Each case means a parallel translation, a rotational translation and a reductional translation respectively. Though estimated components u and v are real numbers, actual solutions are integral numbers. Therefore extracted values $(u^2+v^2)^{1/2}$ are rounded to integers. The accuracy of results depends on the number of the simultaneous equation and line curvature. The number of simultaneous equation is 20 which is obtained from adjoining pixels on the line pattern. In the parallel translation results are considered to be correct. In the rotational and scale change translation results contain some errors. In these case it is considered that more general conditional methods taken hole contour line into account are required.

4.2.Complicated line pattern matching

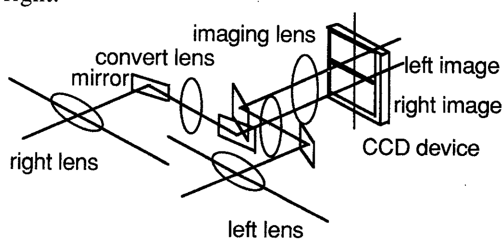
Figure 7(a) shows the complicated line pattern image. Figure 7(b), 7(c) and 7(d) show extracted optical flow by use of the algorithm for complicated line patterns.Each case also means the parallel, rotational and scale change translation respectively. Estimated values $(u^2+v^2)^{1/2}$ are also rounded to the integers. The number of simultaneous equation is 20.These results are almost same as simple case ones.

5.Application of the fast matching algorithm

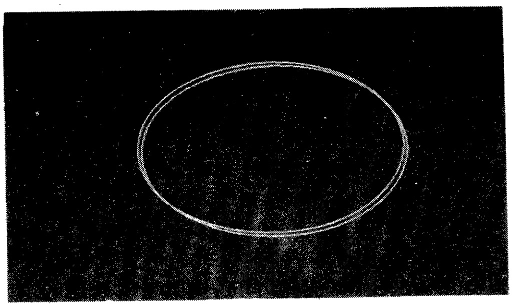
One of the application of the fast line pattern matching algorithm is to interpolate the interval between some algorithms calculation which cost computational time.

Figure 8 shows the image obtained by on board vision system to understand a surrounding scene of the autonomous land vehicle. This image is the original shading image of the complicated line pattern shown in figure 7. The strategy of this vision system is to estimate the distance headway to the vehicle moving ahead by calculating stereo disparities. The image is obtained the stereo vision camera system as shown in figure 9 so that a pair of stereo images are imaged to one imaging device to avoid external synchronous mechanism and electrical difference between two imaging devices. The calculation algorithm of stereo disparities is typical correlation method and which calculation time using on board computer is longer than video rate in spite of the video rate understanding necessity for the vehicle control. The computational time of the fast line pattern matching algorithm is much shorter than the video rate. Moreover the relative distance headway can be estimated by use of optical flow when the vehicle moves toward the optical axis of the on board vision system[11]. In case of the vehicle moves other directions differences between stereo pairs of optical flow give the change of disparities[12]. Consequently the video rate distance understanding is implemented by the combination of typical stereo calculation and extracted optical flow using the fast line pattern matching algorithm.

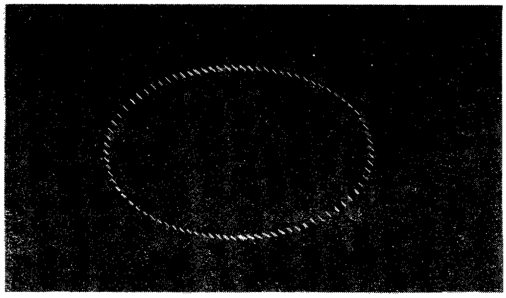
Figure 10 shows the time chart of this combination and figure 11 shows estimated results of the distance headway. In figure 10 calculation time of optical flow is shorter than one video frame time while stereo calculation time is longer than the video rate. Optical flow calculation is implemented by the interrupt process so that relative distance is acquired at video rate. Though stereo calculation time costs almost two video frame time, we can obtain the video rate distance by interpolating the relative distance. The stereo calculation time that costs almost two video frames is only for the illustration and it costs more than ten actually. This algorithm requires only one serial calculation. Figure 11(a) shows the calculation results using only estimated stereo disparities and 11(b) shows the calculation results using the optical flow interpolation. The horizontal axis of the figure shows the horizontal position of the image and the vertical axis represents the distance headway values. The bars are boundaries of the forward vehicle and represented every calculation results overlapped. The vehicle can recognize the video rate distance ahead and the forward vehicle is turning to the right.



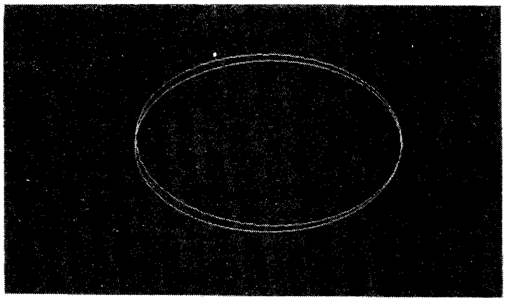
(Figure 9) Stereo vision camera ststem



(a) Parallel translated line pattern

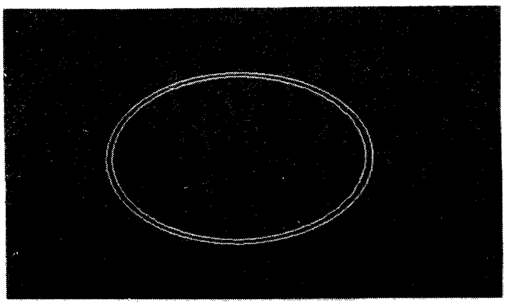


(d) Parallel optical flow

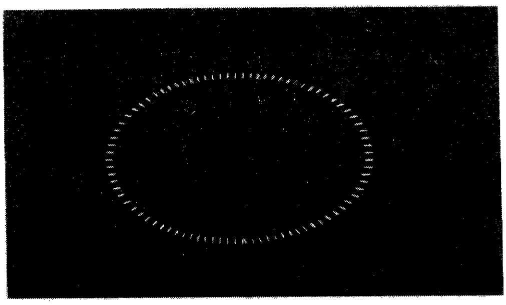


(b) Rotational translated line pattern

(e) Rotational optical flow

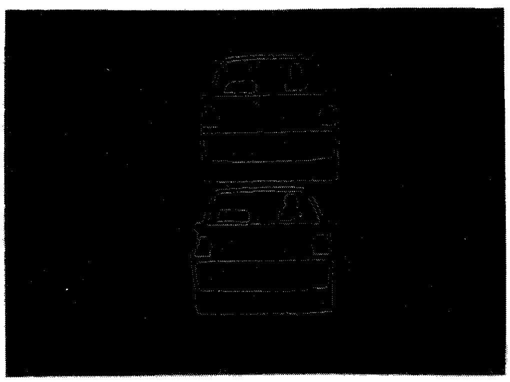


(c) Scale change translated line pattern

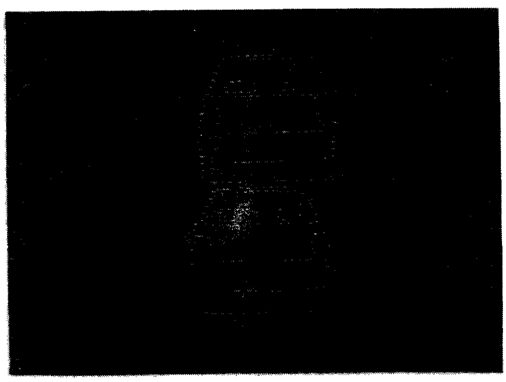


(f) Scale change optical flow

(Figure 6) Each translation and extracted optical flow in simple line patterns

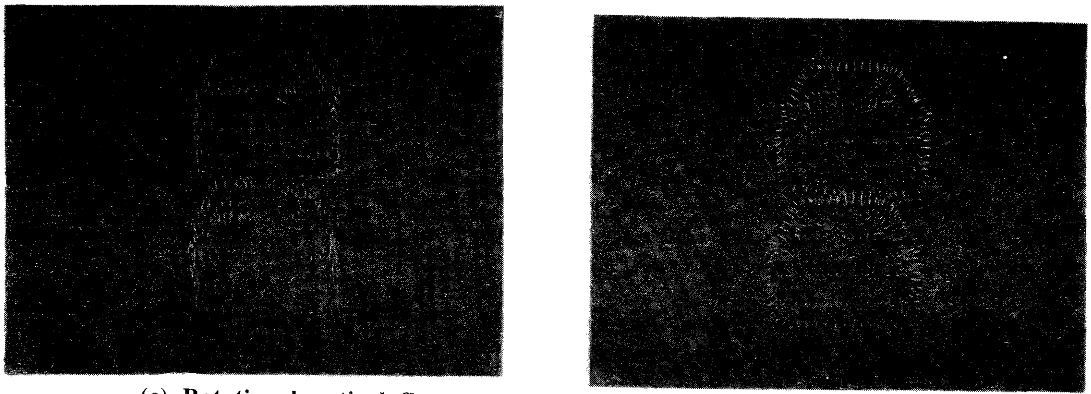


(a) Complicated line pattern



(b) Parallel optical flow

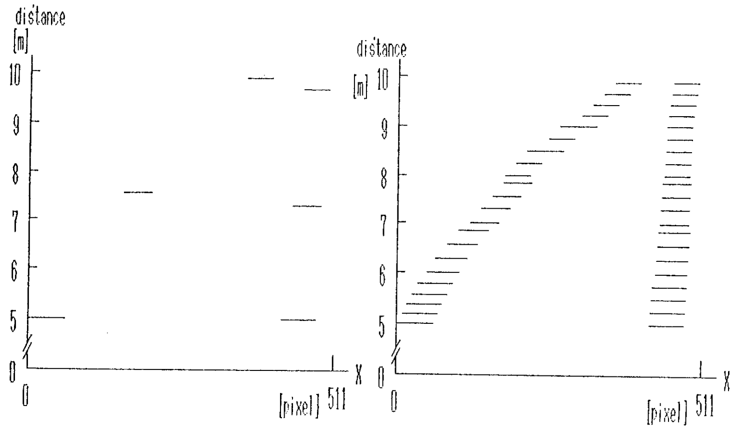
(Figure 7) Complecated line pattern and each extracted optical flow



(c) Rotational optical flow (d) Scale change optical flow

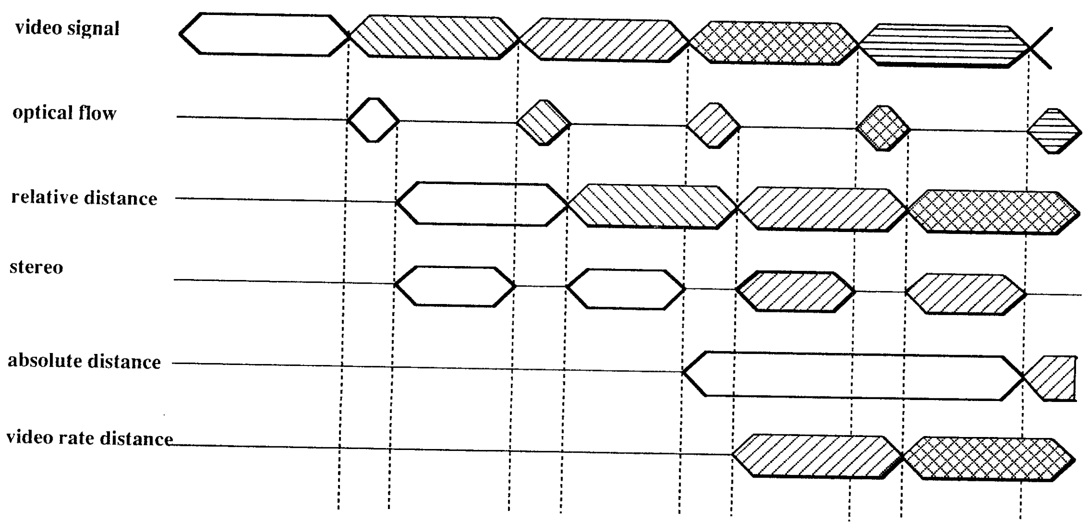
(Figure 7) Complecated line pattern and each extracted optical flow

(Figure 8) Stereo image



(a)Results using only stereo (b)Results using stereo and optical flow

(Figure 11) Estimated time varying results of the distance headway



(Figure 10) Time chart of stereo snd optical flow combination

6.Conclusion

In this paper we described how to apply the gradient method to line pattern binary images and proposed the fast line pattern matching algorithms in simple patterns and complicated patterns by introducing virtual intensities around lines. In the experimental result we show the extracted optical flow in simple and complicated line patterns using our algorithms. In application we show how these algorithm effect in video rate processing.

Compared to the typical correlation algorithm, calculation time is considered to be much shorter because these algorithms require no searching process of corresponding areas. For example in case of the correlation method which use 5×5 pixels window to calculate minimum error, at least 25 times error detect calculations are required and these calculations are increased by sifting the calculation area. Our algorithm requires only chain code detection and minimum distance to the next image line in the simple case. In complicated case though making virtual intensities are required by using average filter, for example 5×5 pixels window, this calculation requires less computational time than the correlation search. Moreover our algorithms have possibilities to work on well in rotational and scale change translation while the correlation method is considered to be weak.

In future we are going to examine the accuracy of results in the rotational and scale change translation, and available area of these fast line pattern matching algorithms using gradient method.

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