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OPTICAL-FLOW ESTIMATION USING SIMPLE GENETIC ALGORITHM FOR ENVIRONMENT MAP GENERATING SYSTEM

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Abstract − A technique to automatically configure an environment map using image processing is proposed in this paper. An autonomous mobile robot, which we are developing travels in indoor environment while referring to the environment map. This technique does not need a great cost in a measurement and can support a change of more indoor environment. Taking the indoor environment by a moving CCD camera, a continuation image is acquired. For each frame image of the continuation image, optical-flow estimation is computed. Straight line elements are extracted from an individual frame image. The straight line elements are chased between frames using an optical-flow estimation. By repeating such an operation, correspondence of straight line elements between the initial frame and the last frame is decided. By applying 3-D stereography to these two frames, 3-D information of the indoor environment is detected. In this paper, several techniques and new technique of the optical-flow estimation are explained. By an experiment, the effectiveness of the new technique is shown.

Keywords: optical-flow estimation, genetic algorithm, image processing

1. INTRODUCTION

We are doing research on an autonomous mobile robot travelling in an indoor environment. The autonomous mobile robot travels while referring to map information, or an environment map. The environmental map is defined by top-view information of the indoor environment. The robot travels the indoor environment by comparing data from various sensors equipped on the robot and the environmental map. So far the environment map is created by measurement by a hand. This method requires a great cost in a measurement and cannot support a change of more indoor environment. In order to solve such a problem, we are developing a technique to automatically configure an environment map by using image processing.

A moving CCD camera of the map generating system takes a continuation image as shown in Fig.1. The system extracts straight line elements from each frame image and computes optical-flow estimation for each frame. Both ends of each straight line element are used as characteristic points for the 3-D stereography. By using those results, correspondence between each consecutive frames is taken. Correspondence between the initial and the final frame images is taken by repeating those operations. By applying the 3-D stereography to the initial and the final images, the top-view information of the indoor environment is obtained.

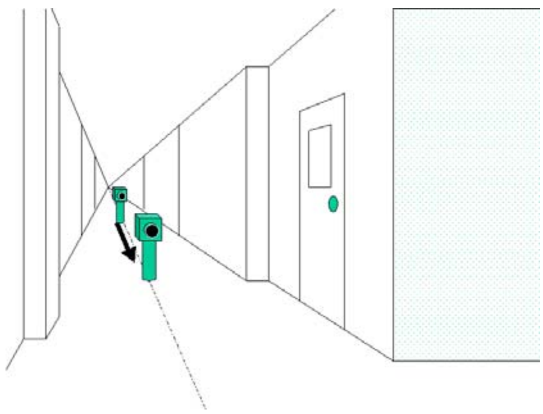


Fig.1. Series pictures taken by a moving CCD camera for the map generating system.

Although we tried some techniques of the optical-flow estimation, there were no practicable techniques. Some of them give result with insufficient resolution in high speed computation. On the other hand, others give good result with very long computing time. Then we propose a new technique of optical-flow estimation by using simple genetic algorithm. The new technique is given by modifying the Block Matching Method (BMM) [4], known as one of powerful technique of optical-flow. Although the BMM must take a lot of time to compute the flow vector, the proposed technique gives a good result within a short time. In this paper, we discuss some techniques of the optical-flow estimation and propose the new technique, applied with the GA, to compute the optical-flow estimation.

2. GENERATION OF ENVIRONMENT MAP

A flow chart of the map generating system is illustrated in Fig.2. First, the system takes the continuation images. Edge strength is detected from each frame image by using Sobel filter. Applying the threshold process to the result of Sobel filter, two-valued image is acquired. The straight line elements are detected form the two-valued image. An example of an original image and a result of the two-valued image after Sobel filtering are shown in Fig.3 and Fig.4 respectively.

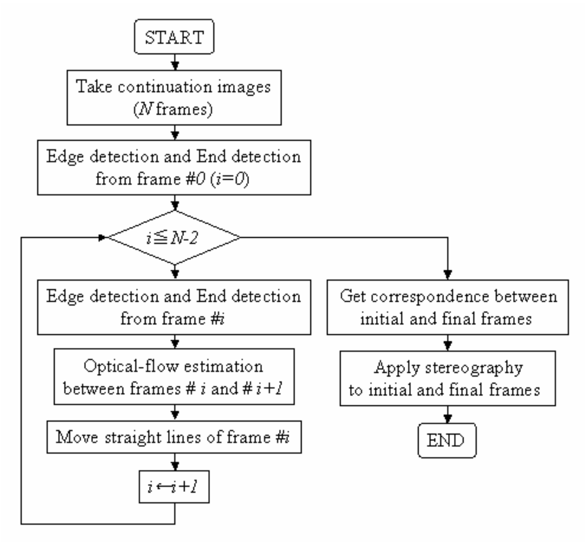


Fig.2. A flow chart of the map generating system.

Fig.3. An original image.

Fig.4. two-valued image after Sobel filtering.

The optical flow estimation is computed between the consecutive frames. The ends of the straight line element of image *#i* are moved according to the optical flow estimation. The moved straight line element of image *#i* is compared to all the straight line elements of image *#i+1*. Among all the elements of image *#i+1*, an element resembling the element of image *#i* is selected. Then correspondence of the straight line elements between the consecutive frames is taken. By repeating these operations until the final frame, correspondence of the straight line element between the initial frame and the final frame is decided. Applying the 3-D stereography as shown by Fig.5 to the initial and the final images, the top-view information of the indoor environment is obtained. Position in the real world is given by the following equations,

$$x = \frac{-x_1 x_2 \left(1 + L/f\right)}{x_2 - x_1}, \tag{1}$$

$$z = \frac{x_2 \left(L + f\right)}{x_2 - x_1}. \tag{2}$$

where the parameters are defined as shown in Fig.5.

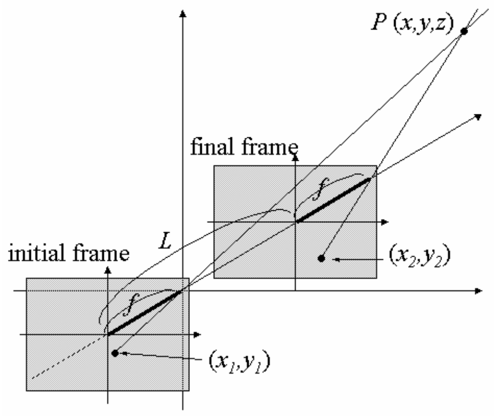


Fig.5. 3-D stereography.

3. OPTICAL-FLOW ESTIMATION

We can roughly classify the techniques to compute the optical-flow estimation into two groups. One of them starts from the following assumption,

$$I(x, y; t) = I(x + \Delta x, y + \Delta y; t + \Delta t). \tag{3}$$

Eq.(3) means that the brightness of the pixel at the point of (x, y), $I(x, y; t)$, is assumed to equal the brightness of the pixel at the point of $(x + \Delta x, y + \Delta y)$, $I(x + \Delta x, y + \Delta y; t + \Delta t)$, when $I(x, y; t)$ moves to the point of $(x + \Delta x, y + \Delta y)$ between consecutive frame images. The right side of Eq.(3) can be expanded as follows, that is Taylor expansion,

$$I(x + \Delta x, y + \Delta y; t + \Delta t) = I(x, y; t) + \frac{\partial I}{\partial x}\Delta x + \frac{\partial I}{\partial y}\Delta y + \frac{\partial I}{\partial t}\Delta t. \tag{4}$$

In this expansion, we assumed that terms with larger order number could be ignored, because they are small. By differentiating both side of Eq.(4) by time variable,

t, and by defining as $u = \frac{dx}{dt}$ and $v = \frac{dy}{dt}$, the following constrained equation is obtained,

$$\frac{\partial I}{\partial x}u + \frac{\partial I}{\partial y}v + \frac{\partial I}{\partial t} = 0\,, \tag{5}$$

where the pair (u,v) denotes the flow vector at the point (x,y). The optical-flow estimation, (u,v), can be obtained by calculating backward Eq.(5). Several techniques using different backward calculation under various conditions, such as LMS, have been proposed. Generally, these techniques must give reliability for each estimation result.

The gradient-based method with local optimization is expressed here. Now, the frame is divided into rectangular partial region, which is sized as $M \times N$ [pix^2]. We can assume that optical flow estimation at each pixel in the partial region is equivalent to each other. Therefore, optical flow estimations at all pixels in the partial region must satisfy the only one constrained equation. Acquiring the partial differential coefficients at each pixel, the following simultaneous equations are defined in the partial region,

$$\mathbf{Gf} = -\mathbf{b}\,, \tag{6}$$

$$\mathbf{G} = \begin{bmatrix} \frac{\partial I_1}{\partial x} & \cdots & \frac{\partial I_i}{\partial x} & \cdots & \frac{\partial I_{M\times N}}{\partial x} \\ \frac{\partial I_1}{\partial y} & \cdots & \frac{\partial I_i}{\partial y} & \cdots & \frac{\partial I_{M\times N}}{\partial y} \end{bmatrix}^T, \tag{7}$$

$$\mathbf{f} = [u, v]^T\,, \tag{8}$$

$$\mathbf{b} = \begin{bmatrix} \frac{\partial I_1}{\partial x} & \cdots & \frac{\partial I_i}{\partial x} & \cdots & \frac{\partial I_{M\times N}}{\partial x} \end{bmatrix}. \tag{9}$$

Solving Eq.(6), optical flow vector **f** can be given by the following equation,

$$\mathbf{f} = -\left(\mathbf{G}^T\mathbf{G}\right)^{-1}\mathbf{G}^T\mathbf{b}\,. \tag{10}$$

In another group of the technique, an image subtracted from a partial region of the preceding image of the consecutive two images, defined as a template, is directly searched in the following image. In this search, the following evaluation formula is performed.

$$D(x,y,u,v) = \sum_{n=n_0}^{n_0+P-1}\sum_{m=m_0}^{m_0+Q-1} |\, I(x+m, y+n; t) - I(x+m-u, y+n-v; t+\Delta t)\,|\,. \tag{4}$$

A pair of (u,v) giving the least value of D through the search is decided at the point (x,y). This technique is known as the BMM [4] and requires a lot of computations to search the template in the image. Because when the size of region, which should be sesrched, is $P \times Q$, the number of evaluation time becomes PQ.

4. OPTICAL-FLOW ESTIMATION USING GA

The simple Genetic Algorithm (GA) is applied to the search operation of the BMM [5]. The GA should be simple, because the search of the optical-flow estimation is required quick response. Operation flow of the simple GA is shown in Fig.6. At the beginning of the GA, ten individuals are randomly generated. The individual is coded in genotype as a pair of optical-flow estimation, (u,v). All new individuals are evaluated by the evaluating function Eq.(4). The order of the individuals is decided according to the evaluating function. Now, a finishing condition, which the number of generation, g, is handled here, is checked, where G is defined as ten. And then, four parent individuals are selected according to their order. Finally, six new individuals are reproduced by using crossover operation and by using mutation operation.

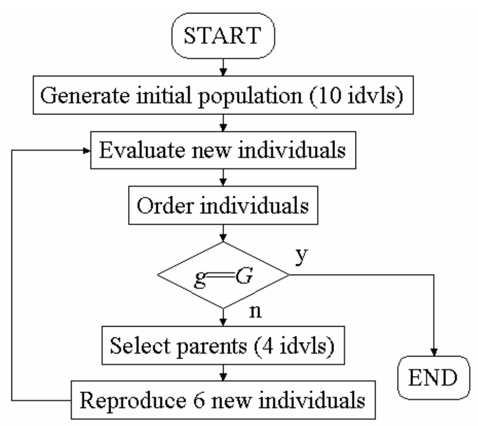


Fig.6. Flow of the simple GA.

The reproduction is illustrated in Fig.7. The parents, p_1-p_4, are selected. These four parents are made survive with no change. From p1 and p2, two new individuals, no.5 and no.6, are reproduced by using the crossover operation and by using the mutation operation with mutation probability 0.01. Next two

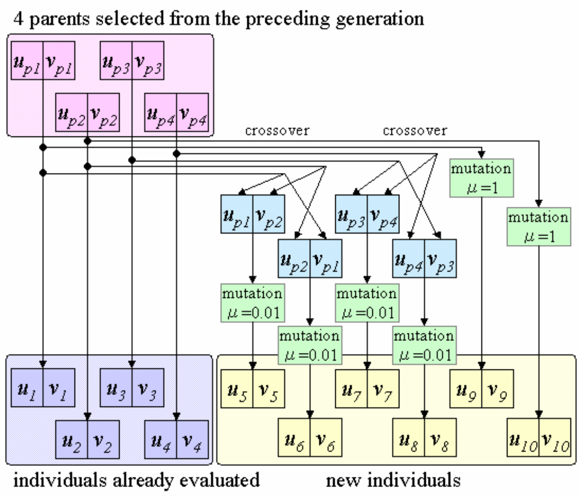
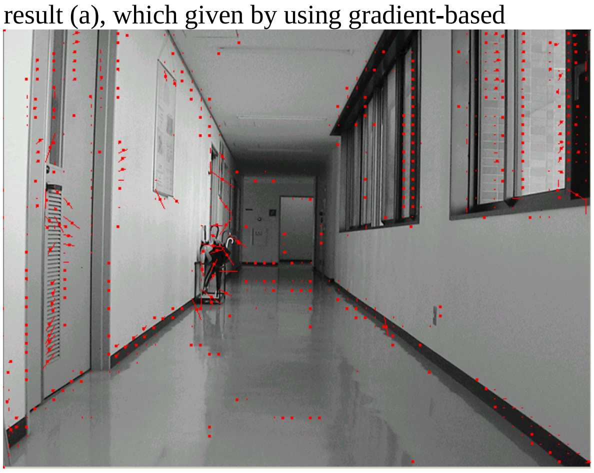


Fig.7. Reproduction of the Simple GA.

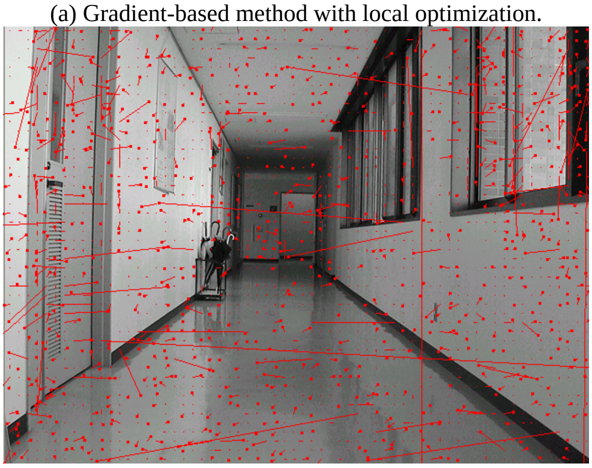
new individuals, no.7 and no.8, are also reproduced by same manner. The last two individuals, no.9 and no.10, are reproduced by using only the mutation operation with mutation probability 1. The four old individuals and six new individuals, totally ten individuals, are survived to the next generation.

5. EXPERIMENT RESULTS

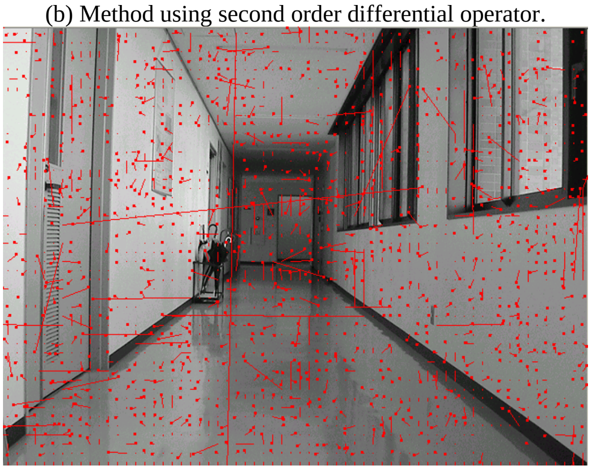
Results of the optical-flow estimation obtained by several techniques are compared. In this experiment, two consecutive frames taken by the moving CCD camera is handled. The results by using several methods of optical-flow estimation are shown in Fig.8. The result (a), which given by using gradient-based



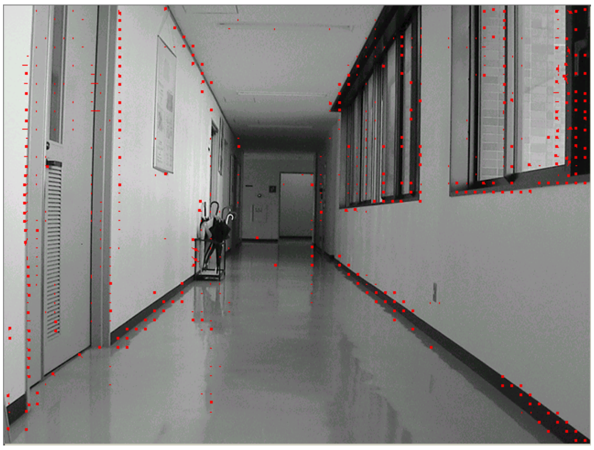
(a) Gradient-based method with local optimization.



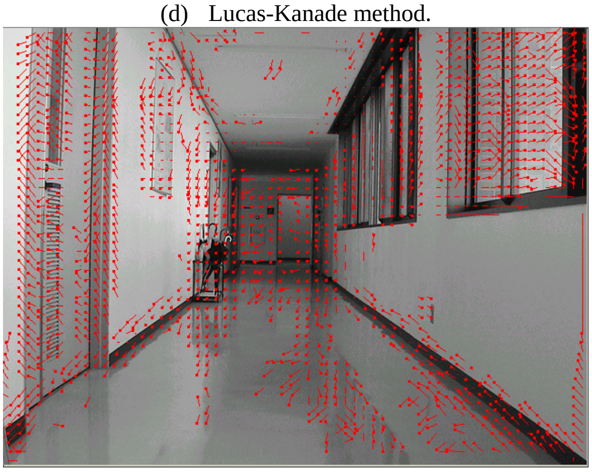
(b) Method using second order differential operator.



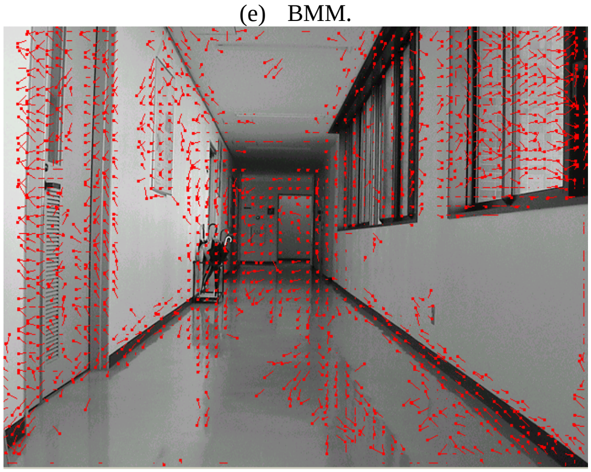
(c) Time-space filtering method.



(d) Lucas-Kanade method.



(e) BMM.



(f) The proposed method using the simple GA.

Fig.8. Comparison of results of the optical-flow estimation.

method with local optimization [1], shows that some correct flow vectors are acquired, though most of the vectors has too small magnitude. In the results (b), which is given by using method using second order differential operator [2], and (c), which is given by using time-space filtering method, there are some vectors showing too big magnitude. And the angles of many vectors are inaccurate. In the result (d), which is given by using Lucas-Kanade method [3], angles of the most of vectors are accurate. However, magnitudes are too small. In the result (e), which is given by BMM, the most of vectors show accurate angles and magnitude. In our experiment, the BMM gives the best optical-flow estimation. Finally, the proposed method using the simple GA gives good flow vectors as shown in (f). However, the result is inferior to the result by the BMM little bit. The proposed method gives adequate optical-flow estimation in our application.

Operation time by using several techniques of optical-flow estimation is timed as shown in table 1. In this experiment, MODEL PCV L-520, manufactured by SONY company, with Pentium 500Mz processor and with 512 MB memory is used. And all the programmes are coded by using Visual C++ ver.6.0, manufactured by Microsoft. The work space of the program is a dialog base of MFC AppWizrd(exe). And the size of the partial region is defined as 10×10 [pix^2].

In the table 1, the first four techniques execute in shorter time. Especially, Lucas-Kanade method can executes within very short time and can gives good results. On the other hand, although BMM requires very long time, it gives very good results. The propose method using the GA gives good results within the shorter time. However, time of the proposed method is longer than that of other first methods. It is required that a technique to reduce the number of evaluation through the search of the GA.

Table 1. Operation time of several techniques

Optical-flow estimation	Operation time [sec]
Gradient-based method with local optimization	0.66
Method using second order differential operator	0.82
Time-space filtering method	0.05
Lucas-Kanade method	0.11
BMM	28.79
The proposed method using the simple GA	9.34

6. CONCLUSION

In this paper, we have proposed a new technique to acquire 3-D information of the indoor environment by using image processing. The information is used for the autonomous mobile robot as the environment map. In the technique, optical-flow estimation and 3-D stereography are used. Especially, optical-flow estimation is very important for this system. Then we tried to implement several techniques of optical-flow estimation. And the new technique of optical-flow estimation using the simple GA is also proposed in this paper. The effectiveness of the proposed technique is explained. However, it is required that a technique to reduce the number of evaluation through the search of the GA.

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