Proposal of a method to extract straight line and circle using one-dimensional histogram

Shota NAKASHIMA and Seiichi SERIKAWA

Graduate School of Electrical Engineering
Kyushu Institute of Technology
1-1 Sensui-cho, Tobata-ku, Kitakyushu-shi, Fukuoka, 804-8550, JAPAN

Abstract: A new method for fast extraction of straight line and circle is proposed in this study. The method utilizes the Polytope method which is one of minimization algorithms. For the extraction of figures, one-dimensional histogram is used. Basically, main algorithm of the extraction of straight line is the same as those of circle and ellipse. Only the definition of histogram and the evaluation function are changed according as figures. By the comparison with Hough transform, it is understood that memory space is very small and processing time is very short.

Keywords: image processing, Polytope method, Hough transform

1. INTRODUCTION

An autonomy robot needs to have an ability of space notation, because it moves and recognizes an object fast. Especially, a robot which moves fast needs to recognize it fast. Thus the fast image processing has been studied [1]. An extraction of straight line and circle is one of the basic problems of image processing. The Hough transform (HT) is the representative method, and it is well used [2][3][4]. It is tough against noises, and the algorithm is simple. However, for extraction of complicated figures, it takes much processing time and needs much memory space. For an improvement of the problems, a new method to extract straight line and circle using one-dimensional histogram is proposed in this study.

2 . Extraction of figures using one-dimensional histogram

A proposed method utilizes the Polytope method and one-dimensional histogram. An application of the Polytope method to extract figures and a procedure of extraction of figures using one-dimensional histogram are mentioned as follows.

2.1 Application of the Polytope method

In this study, one-dimensional histogram is generated from figure. The histogram has two characteristics. (1) The distribution of histogram changes if the parameters representing figure changes. (2) The best parameters is gotten, if the value of most frequency of histogram becomes maximum (see Sect.2.1 for details). By using the Polytope method, the best parameters are searched so that the maximum value of most frequency can be maximum.

The Polytope method is one of minimization algorithms. Since it can get a minimum value no using derived function different from the Newton's method, the concept can be used for search of histogram. In addition, the program size is small. For more details, see Ref. [5] and [6]. For the use, suitable scale factors and initial values must be set. If these are not suitable, the optimum value may not be obtained.

2.2 Procedure to extract figure using one-dimensional histogram

A procedure to extract figure using one-dimensional histogram is mentioned here. The extraction of circle is mentioned as an example. A circle C in Fig. 1(a) is the target circle for extraction. Here, a circle with the radius r and the central coordinate point $p(x_0, y_0)$ is set as shown in Fig. 1(a). The circle is called "search circle" c. Let the distance between central coordinate point $p(x_0, y_0)$ of search circle and a point on circle C be R, and let R/r be d. The value of d is calculated for all pixels on circle C, and the histogram about d is generated. As for extraction of circle, radius r is set to be 1. The example is shown in Fig. 1(b). If the distance between central coordinate point of circle c and that of circle C is far, a distribution of the histogram is gentle and the value of most frequency f_{max} is low as shown in Fig. 1(b). According as the distance is shorter as shown in Fig. 1(c), the value of most frequency f_{max} is higher (Fig. 1(d)). Let the value of d at the position of most frequency f_{max} be d_{max}. If the central coordinate point of search circle c agrees with that of circle C as shown in Fig. 1(e), the value of most frequency f_{max} is the highest (Fig. 1(f)). At the case, the radius R of circle C is obtained as $r \times d_{max}$. A circle is, therefore, extracted by getting the highest value of most frequency f_{max}. We define an evaluation function E so that it becomes small according as the value of f_{max} becomes high. In this study, the central coordinate point $p(x_0, y_0)$ when the evaluation function E is the lowest is obtained by using the Polytope method. In reality, the extraction of circle completes when the evaluation function E is lower than a threshold E_{th}. Next, to extract the other circles, the extracted circle is removed from image data.

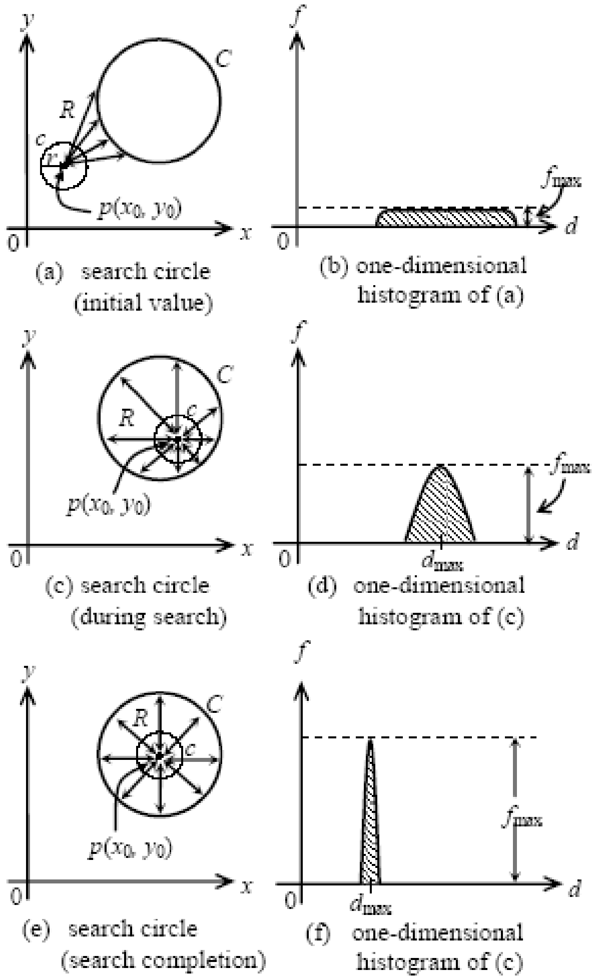


Fig. 1 Outline of search for extraction of circle

By the repetition of the above procedure, multi-circles are extracted.

The above concept is applied to the extraction of ellipse and straight line. First, one-dimensional histogram is generated. The histogram is defined so that parameters representing figure can be extracted when the value of most frequency f_{max} is the highest. Next, the evaluation function E is defined so that it becomes small according as the value of f_{max} becomes high. By the use of the Polytope method, the parameters representing figure is gotten when the evaluation function E is the lowest.

2.3 Extraction of circle and straight line

2.3.1 Extraction of circle

As for extraction of circle, the value of d is calculated for all pixels on circle C as mentioned in Sect. 2.2, and the histogram about d is generated.

To evaluate the histogram, we define the following evaluation function E.

$$E = 1 - \frac{f_{max}}{C_{ir} \times G}, \qquad (1)$$

where, C_{ir} is the circumference length of a circle with radius R, which is obtained as $R = r \times d_{max}$ when the value of histogram is the highest. Symbol G means a weight which is used when d is voted to one-dimensional histogram. The function E is the lowest when the value of f_{max} is the highest. By the use of the Polytope method, the central coordinate point $p(x_0, y_0)$ of circle C is searched so that the function E is the lowest.

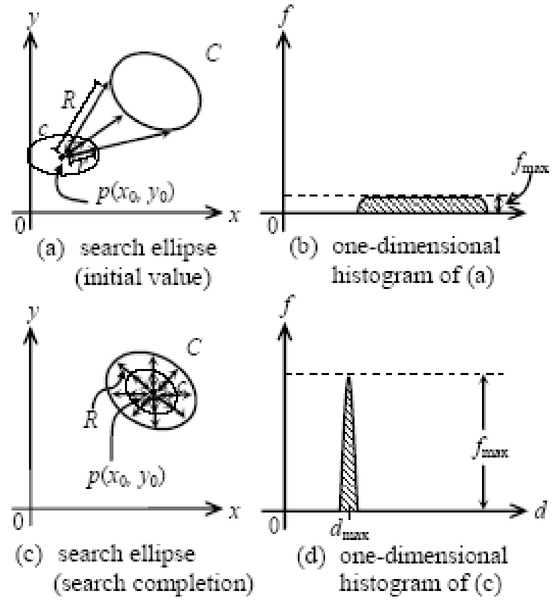


Fig. 2 Outline of search for extraction of ellipse

2.3.2 Extraction of ellipse

The method for extraction of ellipse is an expansion of that of circle.

A histogram is generated as first. To represent ellipse as parameters, central coordinate point $p(x_0, y_0)$, length of major axis a_0, length of minor axis b=1, and rotation angle θ_0 are defined as shown in Fig. 2(a). The ellipse defined by the above is called "search ellipse" c. Let the distance between central coordinate point $p(x_0, y_0)$ of search ellipse and a point on ellipse C be R, let the radius of search ellipse to the direction be r, and let R/r be d. The value of d is calculated for all pixels on ellipse C, and the histogram about d is generated. If the distance between central coordinate point of ellipse c and that of circle C is far, a distribution of the histogram is gentle and the value of most frequency f_{max} is low as shown in Fig. 2(b). According as the distance becomes shorter, the value of most frequency f_{max} becomes higher. Let the value of d at the position of most frequency f_{max} be d_{max}. If $p(x_0, y_0)$, a_0/b, and θ_0 of search ellipse c agree with those of ellipse C as shown in Fig. 2(c), the value of most frequency f_{max} is the highest (Fig. 2(d)). At the case, the length of minor axis of ellipse C is obtained as d_{max}, and the length of major axis corresponds to $a_0 \times d_{max}$.

The evaluation function E for extraction of ellipse is the same as that of circle. That is to say, Eq. (1) is used for the evaluation function of extraction of ellipse.

However, symbol C_{ir} is the circumference length of a ellipse with the length of minor axis d_{max}, and with the length of major $a_0 \times d_{max}$. By the use of the Polytope method, $p(x_0, y_0)$, a_0, and θ_0 of ellipse C are searched so that the function E is the lowest.

2.3.3 Extraction of straight line

The main flow of extraction of straight line is the same as that of circle. In this Section, we explain how to generate histogram and define the evaluation function for straight line.

A straight line l with the inclination θ and across origin point is set as shown in Fig. 3(a). The line l is called "search line". A straight line L in Fig. 3(a) is the target line for extraction. Let the distance between search line l and a point on straight line L be d. The value of d is calculated for all pixels on straight line L, and the histogram about d is generated.

If the inclination of search line l is very different from that of straight line L, the distribution of the histogram is gentle and the value of most frequency f_{max} is low as shown in Fig. 3(b). According as the inclination of l is more similar to that of L, the value of most frequency f_{max} becomes higher. Let the value of d at the position of most frequency f_{max} be d_{max}. If the inclination of l agrees to that of L as shown in Fig. 3(c), the value of most frequency f_{max} is the highest (Fig. 3(d)).

To evaluate the histogram, the evaluation function E is defines as follows.

$$E = 1 - \frac{f_{max}}{N \times G}, \qquad (2)$$

where, N is the number of pixels on straight line L. Symbol G means a weight which is used when d is voted to one-dimensional histogram. The function E is the lowest when the value of f_{max} is the highest. At the case, the distance between the straight line L and origin point is obtained as d_{max}. By the use of the Polytope method, the inclination θ of straight line L is searched so that the function E is the lowest.

2.3.4 Extraction of straight line from multi-figures

If there exist multi-figures on an image data, the wrong straight lines are sometimes extracted by using Eq. (2). For improving it, we examine the pixel number of straight line, whenever a line is extracted. If the number is over a threshold number N_{th}, the line is regarded as true straight line. In the other case, the extracted line is rejected.

3. Experimental results

3.1 Experimental conditions

Image data in Fig. 4, which is used in this experiment, includes four straight lines, two circles and two ellipses. The image size is 320×240 pixels. For the experiments, we used a personal computer (DELL Dimension3100, OS: Windows XP, CPU : Celeron - 2.53GHz).

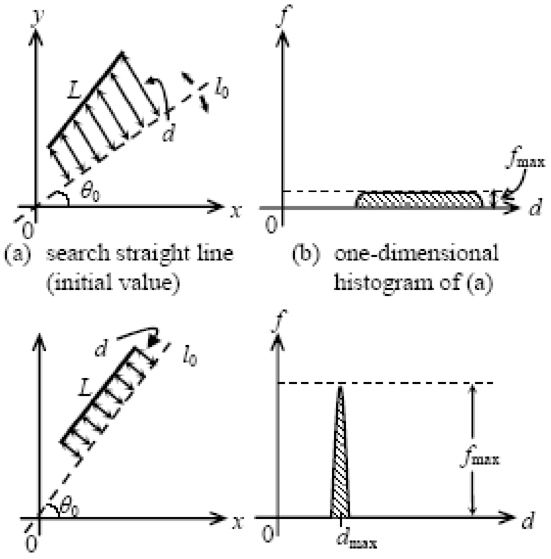


Fig. 3 Outline of search for extraction of straight line

In case of the extraction of straight line, the initial value of θ is set to be 0 and the scale factor is set to be 0.5. The threshold E_{th} of evaluation function E regarded as extraction-completion is set to be 1.0. After one straight line is extracted, it is removed from image data. It is repeated ten times. The procedure mentioned in Sect. 2.3.4 is also practiced for the extraction from multi-figures.

In case of the extraction of circle, the scale factor of central coordinate point $p(x_0, y_0)$ is set to be (10, 10). Here, let the width of image be Xw and the height be Yh. The initial value of $p(x_0, y_0)$ is set to be (Xw/4, Yh/4). After a search using the initial value finishes, the initial value changes. To x axis, x_0 increases Xw/4, y_0 increases Yh/4 to y axis. That is to say, 9 coordinate points are used as the initial points ((3 positions to x axis) × (3 positions to y axis)).

In case of the extraction of ellipse, 9 points are used for the initial value of $p(x_0, y_0)$ as the same way of circle. The initial value of θ is set to be 0 and $\pi/2$, that of length a_0 of major axis is set to be 0.5 and 1.0. For all combination of the above initial values, the search for ellipse is practiced. The scale factor of central coordinate point $p(x_0, y_0)$ is set to be (10, 10), that of θ is set to be 1.0, and that of a_0 is set to be 0.1.

The value of weight G used in Eqs. (1) and (2) is set to be 5 in this experiment.

3.2 Experimental results

Experimental results are shown in Fig. 5. Fig. 5(a) is the result for straight lines, and Fig. 5(b) is the result which is obtained by the application of the procedure of

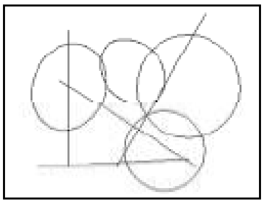
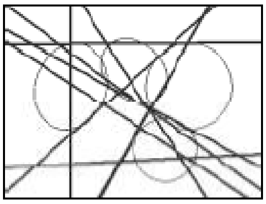
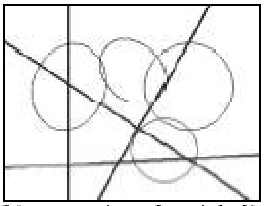


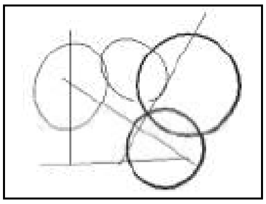
Fig. 4 Image data used in experiment



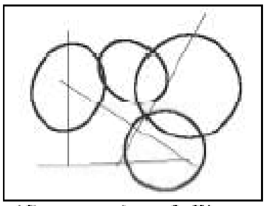
(a) extraction of straight line



(b) extraction of straight line (noise rejection)



(c) extraction of circle



(d) extraction of ellipse

Fig. 5 Experimental results

Sect. 2.3.4 to Fig. 5(a). Although there are wrong straight lines in Fig. 5(a), only correct straight lines are extracted in Fig. 5(b) by applying Sect. 2.3.4. As understood from Figs. 5(c) and (d), the circles and ellipses are correctly extracted in this experiment.

3.3 Comparison of proposed method with Hough transform

Processing time and memory space are examined for the comparison of proposed method with Hough transform (HT). The memory space of proposed method is regarded as the size of one-dimensional histogram. That of HT corresponds to the size of parameter-space. The processing time is regarded as the time from voting start to extraction completion. The results are shown in Tables 1 and 2. As for extraction of straight line, memory spaces of proposed method and HT are 2.4[KB] and 307.2[KB] respectively. Processing times of them are 63[ms] and 48[ms] respectively. As for extraction of circle, memory spaces of them are 1.2[KB] and 122.88[MB] respectively. Processing times of them are 22[ms] and 27.33[s] respectively. As for extraction of ellipse, memory space and processing time are 1.2[KB] and 3.75[s] respectively.

In case of HT, memory space extremely increases when the number of parameters increases. Thus, memory space is huge for circle, whose parameters are more that those of straight line. As the result, the processing time becomes long. Since the number of parameters for ellipse is more than that of circle, memory space can not be gotten in our PC, so we did not measure the processing time. On the other hand, on

Table 1 Comparison of memory space

	straight line	circle	ellipse
propose method [KB]	2.4	1.2	1.2
Hough transform [KB]	307.2	122,880	

Table 2 Comparison of processing time

	straight line	circle	ellipse
propose method [s]	0.063	0.22	3.75
Hough transform [s]	0.048	27.33	

the proposed method, memory space does not increase even if the number of parameters increases. Processing time does not also dramatically increases. Thus, the proposed method is superior to HT about memory space and processing time.

4. Conclusion

A new method to extract straight line and circle using one-dimensional histogram and the Polytope method is proposed in this study. Basically, main algorithm of the extraction of straight line is the same as those of circle and ellipse. Only the definition of histogram and the evaluation function are changed according as figures. By the comparison with Hough transform, it is understood that memory space is very small and processing time is very short.

This research was partly supported by Grant-in-Aid for Scientific Research(C), 19500478.

REFERENCES

[1] Saji Motoki, Ueno Atsushi, Takeda Hideaki : "A Robot System to Recognize and Manage Unfixable Objects in the Office Environment", IEICE technical report, Vol.99, No.717, pp.1-8(2000)
[2] Toshi Minami, Osamu Nakamura : "Image engin-eering", Corona Publishing Co., pp.103-106(2000)
[3] Bahram Javidi, Joseph L.Horner : "REAL-TIME OPTICAL INFORMATION PROCESSING", Academic Press, pp.56-57 (1994)
[4] Eilliam K.Pratt : "DIGITAL IMAGE PROCESSI-NG–Second Edition", wiley&Sons, pp.613-614 (1991)
[5] Haruhiko Okumura : "An algorithm encyclopedia using C", Gijutsu-Hyohron Co., p.262(2006)
[6] W. H. Press, B. P. Flannery, S. A. Teulolsky, W. T. Vetterling : "Numerical Recipes-The Art of Scientific Computing", Cambridge University Press, pp.289-293 (1987)

