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Image Matching Algorithm Based on Grayscale and Its Improvement

Kun Jia
School of Computer Science
Beijing University of Posts and Telecommunications
Beijing, China
buptjiakun@gmail.com

***Abstract*—Image matching algorithm is composed of two parts, which are the algorithm based on the grayscale of the image directly and the algorithm based on the feature of physical shape and the advanced feature of the image. In this paper, two algorithms (correlation coefficient and histogram) based on the grayscale were analyzed and improved. During the process of the algorithm of histogram, two sequences (referential sequence and comparative sequence) are created according to the grayscale of the template image and the real-time sub-image. Compare and calculate the relational degree between the two sequences. The higher the relational degree is the closer to the best matching position. And the algorithm of histogram was improved through the cosine correlation to increase the matching velocity. Both of the two algorithms use the principles (from coarsely to finely, from partial template to whole, interlaced every column) to achieve improvement.**

Keywords—image matching; correlation coefficient; histogram; cosine correlation

I. INTRODUCTION

Image matching is an extremely significant task in computer vision research [1]. It is mainly for finding the area that similar to the template image in the real-time image which is caught under the conditions of different times and different shooting angle. Applications that image matching technology involved in can be extended to industrial test, terrain matching, aircraft navigation, automatic monitoring in industrial pipeline, medical diagnostics, natural resources analysis, meteorological prevision, character recognition, etc [2].

Frequently-used image matching algorithms include two categories: grayscale-based image matching algorithm and feature-based image matching algorithm [1]. Grayscale-based image matching algorithm, which is from a statistical point of view, regards the image as a two-dimensional signal, and uses statistical methods to obtain the correlation coefficient between signals. The higher the correlation coefficient is the closer to the best matching position. Grayscale-based image matching algorithm is simple, but the calculation is too large. In feature-based image matching algorithm, many features (such as point, line, and surface) are extracted from the image [3]. And this algorithm achieves the task through matching the features. Because the number of the image features is much less than the number of pixels in the image, the calculation is reduced. But feature-based image matching algorithm's calculation of correlation coefficient is more complex than Grayscale-based image matching algorithm.

Both the correlation coefficient matching algorithms and the histogram matching algorithms emphasize the degree of similarity between images. In this paper, we analyze and improve these two image matching algorithms.

II. ALGORITHM BASED ON CORRELATION COEFFICIENT

A. Algorithm Description

The basic thought of algorithm: Move the template image (T) on the real-time image (R), and find the correlation coefficient (C) on every position of R.

If the point (0, 0) on T overlaps with the point (m, n), we say that T moves to the point (m, n) on R.

When T moves to the point (m, n) on R, the C(m, n) (Fig. 1) [4]:

$$C(m,n)=\frac{\sum_{(i,j)\in T}\left(R(m+i,n+j)-\overline{R}(m,n)\right)\cdot\left(T(i,j)-\overline{T}\right)}{\sqrt{\sum_{(i,j)\in T}\left(R(m+i,n+j)-\overline{R}(m,n)\right)^2}\cdot\sqrt{\sum_{(i,j)\in T}\left(T(i,j)-\overline{T}\right)^2}}$$

$$\overline{R}(m,n)=\frac{1}{K}\sum_{(i,j)\in T}R(m+i,n+j)$$

$$\overline{T}=\frac{1}{K}\sum_{(i,j)\in T}T(i,j)$$

Fig. 1. The Correlation Coefficient at Point (m, n)

K is the number of pixels in T. At the point (i, j) in T, the gary value is T(i, j). At the point (i, j) in R, the gary value is R(i, j).

C(m, n) describe the local correlation between T and R. No matter what the content is in T and R, the value of C(m, n) is between -1 and 1. When the value of C(m, n) is 1, it means that there is a greatest similarity between T and R. And there is a greatest difference between T and R when the value is equal to -1. When we find the largest value of correlation coefficient at the point (m, n), point (m, n) is the best matching position.

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B. *Algorithm Analysis*

Assuming that the width and the height of T are Wt and Ht, and the number of pixels in T is Kt (Kt=Wt × Ht).

Assuming that the width and the height of R are Wr and Hr, and the number of pixels in R is Kr (Kr=Wr × Hr).

According to this algorithm, we have to calculate C(m, n) on every possible point. Through the Fig. 2 we are know that the number of the possible points is PPN (PPN=(Wr-Wt+1) × (Hr-Ht+1)).

According to Fig. 1, when we calculate C(m, n), there are (9*Kt) times of operations have to be execute.

After the get all the C(m, n), we have to find the largest one. The time complexity is O(Kt).

So we have to calculate (PPN × (9 × Kt)+Kt) times before we find the best matching point. The time complexity is O(Kt × Kr).

After the analysis above, the disadvantages of the algorithm are listed below:

- The calculation times of C(m, n) is large.
- The calculation of single C(m, n) is large.
- The calculation of finding the largest C(m, n) is large.

C. *Algorithm Improvement*

Through the algorithm analysis above we know that the main disadvantage is large amount of calculation. Next, we will focus on the three disadvantages to improve the algorithm.

To reduce the calculation times of C(m, n), we can match the image from coarsely to finely by interlacing every column. The matching points are showed in Fig. 3.

The gray squares in Fig. 3 are the points on which the correlation coefficient we need to calculate during the rough matching stage. After the rough matching stage, we find the largest correlation coefficient among them.

Assume that point A has the largest correlation coefficient. During the fine matching stage, we have to get the correlation coefficients on the nine points in the black pane. And the point (among the nine points) which has the largest value of correlation coefficient is the best matching position.

- During the rough matching stage, the number of the possible points is PPN/4. During the fine matching stage, the number of the possible points is nine. So C(m, n) will be calculated (PPN/4+9) times.

After we reduce the calculation times of C(m, n), the calculation of finding the largest C(m, n) is reduced in the same time.

- But The time complexity is also O(Kt)

To reduce the calculation of single C(m, n), we can take two measures. One is simplified formulas; the other one is match the image with the partial template.

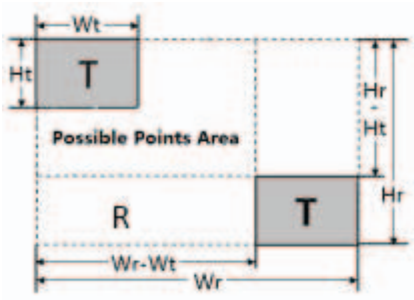

Fig. 2. The possible points area of R

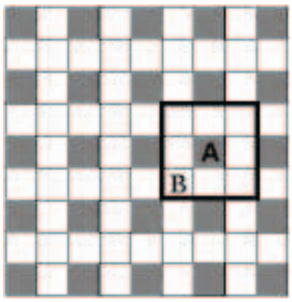

Fig. 3. The schematic of matching points

In the first measure, we integrate the formulas in Fig. 1 into the formula in Fig. 4. Then we begin to simplify the formula

$$C(m,n) = \frac{\sum_{(i,j)\epsilon T}\left(R(m+i,n+j)\cdot T(i,j)\right) - \sum_{(i,j)\epsilon T} R(m+i,n+j)\cdot \bar{T}}{\sqrt{\sum_{(i,j)\epsilon T} R(m+i,n+j)^2 - \left(\sum_{(i,j)\epsilon T} R(m+i,n+j)\right)^2/K}\cdot\sqrt{\sum_{(i,j)\epsilon T}(T(i,j)-\bar{T})^2}}$$

Fig. 4. The formula after integration

Assuming that (in Fig. 5):

$$\sum RT = \sum_{(i,j)\epsilon T}\left(R(m+i,n+j)\cdot T(i,j)\right)$$
$$\sum R = \sum_{(i,j)\epsilon T} R(m+i,n+j)$$
$$\sum R2 = \sum_{(i,j)\epsilon T} R(m+i,n+j)^2$$
$$\sum T = \sum_{(i,j)\epsilon T} T(i,j)$$
$$\sum T2 = \sum_{(i,j)\epsilon T} T(i,j)^2$$
$$\sqrt{\sum_{(i,j)\epsilon T}(T(i,j)-\bar{T})^2} = \sqrt{\sum T2 - \sum T^2/K}$$

Fig. 5. The formulas for simplify

Put the formulas in Fig. 5 in the formula in Fig. 4, we get a simple formula for C(m, n):

$$C=(\sum RT-\sum R\times\sum T/Kt)/((\sum R2-\sum R^2/Kt)^{1/2}\times(\sum T2-T^2/Kt)^{1/2}) \quad (1)$$

When T is definite, ∑T and (∑T2-∑T2/Kt)1/2 are constant, so during the process of image matching they only need to calculate once. While ∑RT, ∑T and ∑R2 must be calculate once for each C(m, n).

- After the simplified the formula, the number of operations have to be execute down to (5 × Kt).

In the second measure, we use the partial template image (partial T) for the rough matching stage and use T for the fine matching stage.

- If the number of the partial T is Kt/N, the number of operations used for each C(m, n) is (5 × Kt/N).

Through the algorithm improvement we decrease the calculation of the whole process, and there is a brief summary below (Tab. Ⅰ):

TABLE I. ALGORITHM PERFORMANCE COMPARISON

Comparative Item	Before	After
calculation times of C	PPN	PPN/4+9
calculation of single C with T	9*Kt	5*Kt
calculation of single C with partial T	/	5*Kt/N
calculation of image matching	9×PPN×Kt+Kt	1.25×PPN×Kt/N+45×Kt+PNN/4+9
time complexity of the algorithm	O(Kt×Kr)	O(Kt×Kr/N)

III. ALGORITHM BASED ON HISTOGRAM

A. Algorithm Description

The basic thought of algorithm: Move the template image (T) on the real-time image (R), and find the relevancy of histogram information (E) on every position of R.

Histogram is a kind of frequency distribution, and it describes the frequency of the different intensity values in the image [4]. For example, Fig. 6 is the classic Lena image and its histogram.

If the point (0, 0) on T overlaps with the point (m, n), we say that T moves to the point (m, n) on R.

Assuming that at the point (m, n), the histogram information sequence of sub-image of R is X. The histogram information sequence of T is Y.

$$X = \{ X(0), X(1), \ldots, X(255) \} \tag{2}$$

$$Y = \{ Y(0), Y(1), \ldots, Y(255) \} \tag{3}$$

The X(i) ($0 \le i \le 255$) in (2) is the number of the points in R whose gray value is equal to i. The Y(i) ($0 \le i \le 255$) in (3) is the number of the points in T whose gray value is equal to i.

When T moves to the point (m, n) on R, the E(m, n) is relevancy of X and Y. No matter what the content is in T and R, the value of E(m, n) is between -1 and 1. When the value of E(m, n) is 1, it means that there is a greatest similarity between T and R. And there is a greatest difference between T and R when the value is equal to 0. When we find the largest value of relevancy at the point (m, n), point (m, n) is the best matching position.

Fig. 6. The Lena image and its histogram

B. Algorithm Analysis

There is a common method to calculate the relevancy of X and Y: a grey correlation analysis method [5].

For this method, there are a lot of kinds of grey correlation computation models [6], but many of them have a fuzzy distinguish between positive and negative correlation of the sequence. Some computation models can distinguish between positive and negative correlation, but they do not consider as a whole. They would get the opposite result with actual situation.

Example:

We have two lists: Y1 and Y2, as follows:

Y1 = {1.2, 1.7, 2.2, 2.3, 2.5}

Y2 = {1.4, 1.5, 1.6, 1.5, 1.6}

According to the T correlation computation model [6], the relevancy of Y1 and Y2 is -0.025. The result is obviously not right, because the two sequences is obviously positive correlation from the overall view.

C. Algorithm Improvement

Cosine correlation is a similar computation model [7-8]. It can effectively quantify the correlation from the overall perspective.

The formula and process of the cosine correlation is described below:

Assuming that the incremental sequences of X and Y (△X in (4) and △Y in (5)), and the relevancy between the incremental sequences (R(i) in Fig. 7) [9].

$$\Delta X = \{\Delta X(i) = X(i+1) - X(i)\} \tag{4}$$

$$\Delta Y = \{\Delta Y(i) = Y(i+1) - Y(i)\} \tag{5}$$

$$R(i) = \begin{cases} 1 & \Delta X(i)=0 \text{ 且 } \Delta Y(i)=0 \\ \mathrm{sgn}(\Delta X(i))\times\cos\beta_i & \Delta X(i)\neq 0 \text{ 且 } \Delta Y(i)=0 \\ \mathrm{sgn}(\Delta Y(i))\times\cos\beta_i & \Delta X(i)=0 \text{ 且 } \Delta Y(i)\neq 0 \\ \mathrm{sgn}(\Delta X(i)\times\Delta Y(i))\times\cos\beta_i & \Delta X(i)\neq 0 \text{ 且 } \Delta Y(i)\neq 0 \end{cases}$$

Fig. 7. The relevancy between the incremental sequences R(i)

If R(i)>0, it is a positive correlation; if R(i)<0, it is a negative correlation. Among the R(i), $\beta i = \tan^{-1}[|(\Delta Y(i) - \Delta X(i))/(1+\Delta Y(i)\times\Delta X(i))|]$.

Assuming that, m+ is the number of positive correlation, m- is the number of negative correlation, A_+ is the average of positive correlations, and A_- is the average of negative correlations.

The relevancy of X and Y is:

$$E = (W_+\times m_+\times A_+ + W_-\times m_-\times A_-)/(n-1) \ (n=256) \tag{6}$$

Among E in (6), W_+ is $(m_+/(n-1)+(|A_+|/(|A_+|+|A_-|)))/2$, W_- is $(m_-/(n-1)+(|A_-|/(|A_+|+|A_-|)))/2$.

Now, we use the cosine correlation to calculate the relevancy of Y1 and Y2.

△Y1 = {0.5, 0.5, 0.1, 0.2}

△ Y2 = {0.1, 0.1, -0.1, 0.1}

According to the formulas above, the E is 0.35. So the relevancy of Y1 and Y2 calculate through the cosine correlation is more reasonable.

As well as the improved algorithm based on correlation coefficient, the algorithm based on histogram can also match the image from coarsely to finely by interlacing every column to reduce the amount of calculation, and improve the matching speed.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

A. Experimental Conditions

- Experimental Environment: Eclipse.
- Language: Java.
- CPU: Pentium(R) Dual-Core E5700 @ 3.00GHz.
- RAM: 2.00GB
- System Type: 32-bit operating system

The basic data of the experiment:

- T (Fig. 8): width, 100; height, 100.
- R (Fig. 9): width, 512; height, 512.
- T is on the point (248, 230) of R.
- Unit of Matching Time: nanosecond.

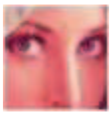

Fig. 8. The template image T (100×100)

Fig. 9. The real-time image R (512×512)

B. Experimental Procedure and Data Results

The experiment will be carried out in four algorithms of image matching. These four algorithms are: algorithm based on correlation coefficient (algorithm 1), improved algorithm based on correlation coefficient (algorithm 2), algorithm based on histogram (algorithm 3) and algorithm based on histogram (algorithm 4).

- Algorithm 1:

The result of algorithm 1 is in Tab. II:

TABLE II. THE RESULT OF ALGORITHM 1

Best Matching Position	Correlation Coefficient	Matching Time (nanosecond)
(248,230)	0.9962200	14851521914

- Algorithm 2 (T is four times the size of partial T):

The best matching position in rough matching stage is (249, 229)

So the nine points during the fine matching stage are: (248, 228), (248, 229), (248, 230), (249, 228), (249, 229), (249, 230), (250, 228), (250, 229), (250, 230).

The result of the fine matching stage is in Tab. III:

TABLE III. THE RESULT OF FINE MATCHING STAGE IN ALGORITHM 2

Researched Matching Position	Correlation Coefficient
(248, 228)	0.9056316
(248, 229)	0.9692893
(248, 230)	0.9962200
(249, 228)	0.8973183
(249, 229)	0.9497826
(249, 230)	0.9663996
(250, 228)	0.8631675
(250, 229)	0.8977658
(250, 230)	0.9038540

Find the largest value of correlation coefficient. The result of algorithm 2 is in Tab. IV:

TABLE IV. THE RESULT OF ALGORITHM 2

Best Matching Position	Correlation Coefficient	Matching Time (nanosecond)
(248,230)	0.9962200	910288593

- Algorithm 3:

The result of algorithm 1 is in Tab. V:

TABLE V. THE RESULT OF ALGORITHM 2

Best Matching Position	Correlation Coefficient	Matching Time (nanosecond)
(248,230)	0.99999994	13719286376

- Algorithm 4 (T is four times the size of partial T):

The best matching position in rough matching stage is (249, 229)

So the nine points during the fine matching stage are: (248, 228), (248, 229), (248, 230), (249, 228), (249, 229), (249, 230), (250, 228), (250, 229), (250, 230).

The result of the fine matching stage is in Tab. VI:

TABLE VI. THE RESULT OF ALGORITHM 2

Researched Matching Position	Correlation Coefficient
(248, 228)	0.33334436
(248, 229)	0.34675925
(248, 230)	0.99999999
(249, 228)	0.33604728
(249, 229)	0.37030640
(249, 230)	0.34802884
(250, 228)	0.31883620
(250, 229)	0.34918971
(250, 230)	0.32967878

Find the largest value of correlation coefficient. The result of algorithm 4 is in Tab. Ⅶ

TABLE VII. THE RESULT OF ALGORITHM 2

Best Matching Position	Correlation Coefficient	Matching Time (nanosecond)
(248,230)	0. 99999999	2675174459

C. Experimental Results Analysis

The four best matching positions get through the four algorithms are all consistent with the position of the template image in real-time image. The results show that in the case of no geometric deformation and no brightness change, four algorithms can be carried out a right position in the experiment.

The contrast of the four algorithms' matching time (Tab. Ⅷ):

TABLE VIII. THE RESULT OF ALGORITHM

Matching Algorithm	Matching Time *(nanosecond)*
Algorithm based on correlation coefficient	14851521914
The improved algorithm based on correlation coefficient	910288593
Algorithm based on histogram	13719286376
The improved algorithm based on histogram	2675174459

The improved algorithm based on correlation coefficient's matching time decrease a lot. The matching time is one-sixteenth of the original. The degree of the increase in matching speed associated with the matching strategy of interlaced every column, also related to the size of the partial template image. The smaller the size is, the smaller the calculation is. The smaller the calculation is, the shorter the matching time is. While the size of the partial template image is too small, it would affect the accuracy of image matching, so we should select the size carefully.

The improved algorithm based on histogram's matching time decrease too, but not as much as the previous algorithm. The matching time is one-fifth of the original. The degree of the increase in matching speed also associated with the matching strategy of interlaced every column, also related to the size of the partial template image. Because the calculation is related to the constant N (the kinds of gray value, 256), the calculation of the algorithm is stable. So when the template image is large enough, the matching time of this would be smaller than the previous improved algorithm's.

V. CONCLUSIONS

The matching time of the algorithm based on correlation coefficient decrease most after improvement, but it is sensitively affected by the size of the image. The algorithm based on histogram with cosine correlation improves the matching speed but not significantly, and it make the matching time good in stability because it relies on the characteristic of the image. In this paper, we improved the matching speed and ensure the correctness by using the optimization calculation, cosine correlation and the principle (from coarsely to finely, from partial template to whole, interlaced every column).

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