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The Study of GPS Vision Navigation System of Multi-stage Real-time Matching Algorithm

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Abstract

There exists the problem of low accuracy, instability and costly mobile communication positioning in GPS navigation. The vision orientation system as an auxiliary navigation method can realize the function of high precision positioning within a large range. This paper introduces a matching constraint and layer-by-layer search structure which is suitable for GPS vision navigation system, and puts forward a feature aided multi-stage matching algorithm. The algorithm firstly makes the match of the more obvious characteristics points, then the matched points information are used to determine the subsequent points general disparity range through the geometric constraints, thus improving the matching speed and accuracy. Using different types of outdoor natural topographic map matching experiments were conducted. Experimental results show that the multi-stage matching algorithm introduced in this paper is better than the basic area matching algorithm in matching accuracy and speed.

Keywords: *GPS Vision Navigation System, Line Constraint, Feature Matching, Multi-stage Matching*

1. Introduction

Real-time navigation and positioning technology get more and more widely used in the modern society, especially in the car and handheld GPS navigation field. GPS navigation greatly facilitates people's life, at the same time, in the face of new increasing demand, began to reveal some inherent shortcomings. For example, the civil GPS signal in the best case also has the positioning error of about 10 meters, and can not be directly used for the vehicle automatic driving [1]. In addition, because of signal attenuation caused by the buildings, the application of GPS in the indoor environment and city is prone to instability phenomenon. By the use of triangulation within the mobile communication network high precision positioning can be achieved, but because of the need to set up a large number of base stations, there is a high cost and limited coverage problem [2]. Vision-based localization system which is based on visible light image information, only need the image information obtained by camera and can achieve high precision positioning in a larger range, while the consumer-level cameras are widely exist in mobile phones and digital cameras [3]. Therefore, vision positioning can effectively solve the existing problems of low accuracy, instability and costly mobile communication positioning in GPS navigation. As an auxiliary means of navigation, it can achieve high precision positioning in large range to meet more needs of production and life.

The key technology of GPS vision navigation system is the feature matching. Although the feature matching in some experimental demonstration shows a high precision and stable performance, showing its great potential in high precision navigation, but its application in practical use is still facing a series of challenges [4]. First, the accuracy of the feature

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matching is still to be improved. In stereo vision measurement feature matching is used for stereo matching and sequence tracking, and its matching accuracy and robustness directly determine the performance of vision navigation. But the existing algorithms can not meet the requirements in accuracy and stability. From the feature extraction, description, matching algorithm to mismatch removal all need to be improved [5, 6].

This paper introduces a matching constraint and layer-by-layer search structure which is suitable for GPS vision navigation system, and puts forward a feature aided multistage matching algorithm. The algorithm firstly makes the match of the more obvious characteristics points, then the matched points information are used to determine the subsequent points general disparity range through the geometric constraints, thus improving the matching speed and accuracy. Using different types of outdoor natural topographic map matching experiments were conducted. Experimental results show that the multistage matching algorithm introduced in this paper is better than the basic area matching algorithm in matching accuracy and speed.

2. Matching Constraint

GPS vision navigation system angle is relatively large, in the range of about ten meters to tens of meters. While the camera shooting height generally ranges between 1 meter and 2 meters [7]. From the line of the maximum disparity value in the bottom of images, the minimum distance from each pixel line corresponding scene point to the camera increases line by line, the maximum disparity value reduces line by line. The maximum disparity value of each line will increase only when the surface of convex or concave terrain is perpendicular to the ground and the camera is very close. At the same time, in order to avoid the case that the maximum disparity value points in some lines have not been successfully matched, the algorithm starts the match from the maximum disparity value line, in the several front lines only using the maximum disparity constraint to limit the search scope. Then consider N lines as a unit, and amplify appropriately the actual matching maximum disparity value which is got in the N lines, and make the new figure as the upper limit of disparity in the next N lines, so as to further narrow the search scope. So, except the original several lines, disparity unilateral change constraints can replace the maximum disparity constraint which can be used to limit the scope of the search [8].

3. Multi-stage Real-time Matching Algorithm

In this paper the basic idea of multi-stage matching algorithm is to divide the matching points into several parts according to the gray gradient size [9, 10]. The maximum gradient part will be matched in the first stage, then the smaller gradient parts will be matched in the following stages. In the first stage, preliminary matching results are used to calculate each line's reference disparity. In the second stage, the first stage matching results are used to calculate the reference disparity. And in the third stage, the first two stages matching results are used. And the cycle repeats.

In the first stage, the reference disparities are calculated by using the preliminary matching results. Firstly, conduct feature matching for a small number of points in the maximum gray gradient part of the image, then detect the matching results. For the line j, detect the matched points from the line J-K to the line j+k (known as the j row groups). If the matching points number is greater than a certain value, take the matched points disparity mean value as the reference disparity of the line J. It can effectively reduce the impact of a small amount of error matching by using the disparity mean value of a large number of matched points in a certain line and its adjacent line as the reference disparity. In the end, conduct linear fitting algorithm towards all lines and the corresponding reference disparities, and get all the reference disparities for all lines in the image. In order to ensure the accuracy of the reference disparity in this stage, it requires the preliminary matching results should make the selected lines distribution wide enough, and the matching points on both sides of the selected lines more enough. If a pixel row reference disparity is defer, when matching in this line the search scope is determined by the following formula:

$$d_{refer} - \delta \leq d \leq d_{refer} + \delta \quad (\delta \text{ can not be too small}) \tag{1}$$

In the following stages a more accurate method is used to calculate the reference disparities. The specific approach is: for the line j, detect the matched points within the group lines. If the matching points number is greater than a certain value, take the matched points disparity mean value as the reference disparity of the line J. Then for the lines between every two such pixel rows, calculate the reference disparity using the disparity linear constraint. Different from the first stage when the scene of the visual field is approximated as a flat surface, now essentially the scene surface is approximated as a number of flat surfaces divided by several pixel lines (as shown in Figure 1), which is obviously more accurate approximations on the scene surface, thus the obtained reference disparity is more accurate. Accordingly, using formula (1) to limit the search scope can make δ smaller than that in the first stage.

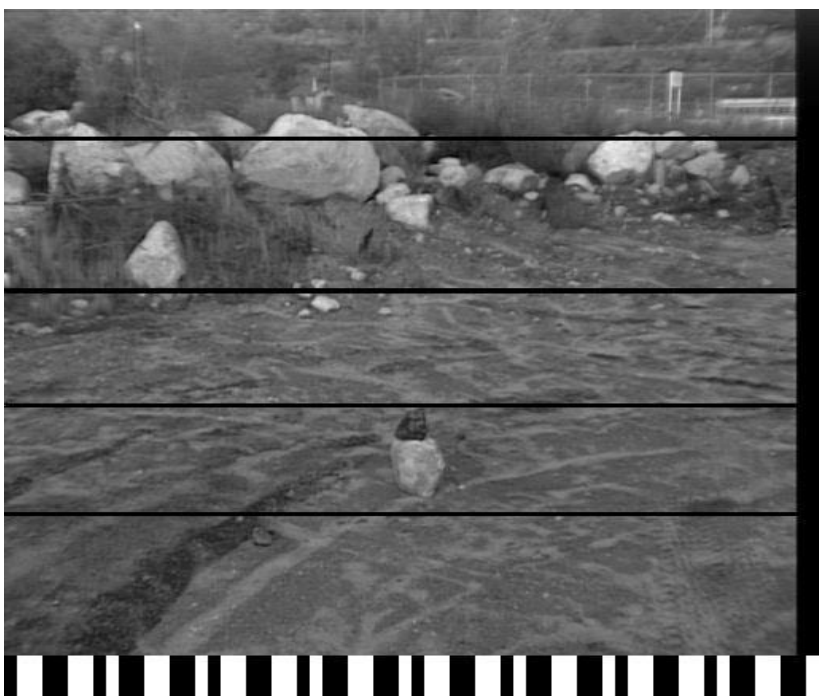


Figure 1. A Scene Surface Approximated by Several Planes

3.1. Selection of Feature Points

The rule of points classification is based on the gray gradient size of the points, which actually reflects the feature's obvious degree of the points. In the experiment, operator Roberts which need less amount of calculation is adopted. First of all, figure out the distribution of gradient values of the points in the reference map, then determine the gradient threshold TH_1, TH_2 and TH_3 of the matching points in the first three stages. In each stage all the points which are not matched and greater than the threshold value are the points which will be matched in this stage. The method to determine the TH_3 are as follows: in the image the points for which the gradient is greater than the t_1 account for 90% of the total points, t_2 is the reliable matching results' minimum gradient value obtained by correlation algorithm using the image points, and $TH_3 = \max(t_1, t_2)$. After determining TH_3, the selection of TH_1, TH_2 makes the number of matching points in the first three stages the same. In the fourth stage, match all the points which have not been matched and the gradient is greater than t_2. In the end, process the rest of still not matched points.

3.2. Determination of the Search Scope

In the first stage, the gradient value of the points which need to be matched is the largest, and the characteristics are the most obvious, relatively it is easy to get the correct matching results. In the following stages the gradient values of the points to be matched decrease, the probability of using the correlational calculation to get the correct matching results falls down. But due to an increase in the number of matched points, the reference disparities calculated become more accurate, thus the search scope becomes smaller and the search result becomes more precise, which helps to improve the matching accuracy.

In the first stage, less information about matching can be available, therefore only reference disparity can be used to limit the search scope, as shown in formula (2). In the second stage, take into account the maximum disparity value d_{line_max} and the minimum disparity value d_{line_min} of the matched points within the group lines, and the search scope of points in a certain line is determined by formula (3).

$$\max\left(d_{refer} - \delta, d_{line\_min} - 1\right) \le d \le \min\left(d_{refer} + \delta, d_{line\_max} + 1\right) \tag{2}$$

In the third stage, with the increase of the matched points, the maximum disparity value d_{zone_max} and the minimum disparity value d_{zone_min} of the points to be matched in the neighbourhood also are used to determine the search scope, as shown in the following formula.

$$\max\left(d_{refer} - \delta, d_{line\_min} - 1, d_{zone\_min} - 1\right) \le d \le \min\left(d_{refer} + \delta, d_{line\_max} + 1, d_{zone\_max} + 1\right) \tag{3}$$

In the fourth stage, the search scope is determined mainly by continuity constraint. The reason is that at that time there are a large number of matched points, and the matched points in the neighborhood can provide the most accurate information for the points which need to be matched.

$$d_{zone\_min} - 1 \le d \le d_{zone\_max} + 1 \tag{4}$$

During the previous matching stages, the search scope determined can contain most of the points' real disparity, but there still may be a part of the matching points which fall outside the scope of search, which may cause failure in matching or mismatching. The points which fail to be matched will be processed in the later stages and the final processing step, while the mismatched points mainly depend on the filter to remove.

3.3. Determination of Matching Criterion

A common assumption in stereo matching is that the gray values of the corresponding matching points in the left and right image are the same. In the practical application the two points gray values may be relatively close, but not exactly the same, and in the two images the difference of the corresponding points gray values are close to each other in a region. Accordingly, in the process of matching figure out the distribution of gray level difference of some matched points, and make it as selection criteria for the candidate matching points to be matched. During the first 3 stages matching points, a multi-feature matching method which consists of the x direction gradient, gradient direction, and gray correlation value is adopted [5].

3.4. Matching Procedure

For the points need to be matched and the candidate matching points in the search region, the matching is conducted according to the following steps:

1) Calculate the difference of the gray value of two points. If it is greater than the threshold, the corresponding candidate matching point are excluded, or enter the next step. Threshold is determined according to the dynamic statistical results of gray level difference of the matched point.

2) Successively calculate the X direction gradient's similarity-index I_{gradx}, gradient direction's similarity-index I_{orient} and the gray correlation value I_{corr} for the candidate matching points and the points need to be matched. The calculation rule is only when the previous index (such as I_{gradx}) is greater than the threshold value, will the later index (such as I_{orient}) be calculated, otherwise the point will be ruled out. The threshold value of I_{orient} is determined by gradient direction constraints, the threshold value of I_{gradx} takes experience value, and the two threshold values take fixed value between stages. The interstage threshold values become smaller with the reduction of the gray gradient value of the points to be matched. The formulae for each index are as follows:

$$I_{gradx} = 1 - \frac{|l\_gradx - r\_gradx|}{|l\_gradx + r\_gradx|} \quad (5)$$

$$I_{orient} = \frac{l\_gradx \cdot r\_gradx + l\_grady \cdot r\_grady}{\sqrt{l\_gradx^2 + l\_grady^2} \cdot \sqrt{r\_gradx^2 + r\_grady^2}} \quad (6)$$

$$I_{corr} = \frac{\sum_{n=-N}^{N}\sum_{m=-M}^{M}\left(f_l(x_l+m, y_l+n) - \overline{f_l(x_l, y_l)}\right)\left(f_r(x_r+m, y_r+n) - \overline{f_r(x_r, y_r)}\right)}{(2N+1)(2M+1)\sigma_l\sigma_r} \quad (7)$$

Among them, l_gradx and l_grady are respectively the direction gradients of the points x and y which need to be matched in the left image. r_gradx and r_grady are respectively the direction gradients of the candidate points x and y in the right image. f_l and f_r are respectively the gray function of the two images. $\overline{f_l(x_l, y_l)}$ and $\overline{f_r(x_r, y_r)}$ are respectively the average gradients in their neiborhood $(2M+1)\times(2N+1)$ of the points to be matched and the candidate points. σ_l and σ_r are respectively the gray standard variances in their neiborhood $(2M+1)\times(2N+1)$ of the points to be matched and the candidate points.

3) When calculating the candidate point of I_{corr}, if I_{corr} is greater than the threshold value, then the whole calculate judgment standard is shown in the following formula:

$$I_{all} = \alpha_1 \cdot I_{gradx} + \alpha_2 \cdot I_{orient} + \alpha_3 \cdot I_{corr} \quad (8)$$

Among them, α_1, α_2 and α_3 are the weights of each index. The threshold of I_{corr} takes the experience value, and it is a fixed value in the stage, but the interstage values become smaller with the reduction of the gray gradient value. In theory, the three weights can adapt to the actual situation better via adaptive change, but this will increase the amount of calculation. The method in this paper is to use different combination of weights in different matching stage, and as far as possible to avoid increasing the amount of calculation in the case of adaptive feature intensity change.

In the fourth stage, the gradient values for most of the points to be matched are relatively smaller, and the feature is not obvious, so they are matched directly by the gray correlation values.

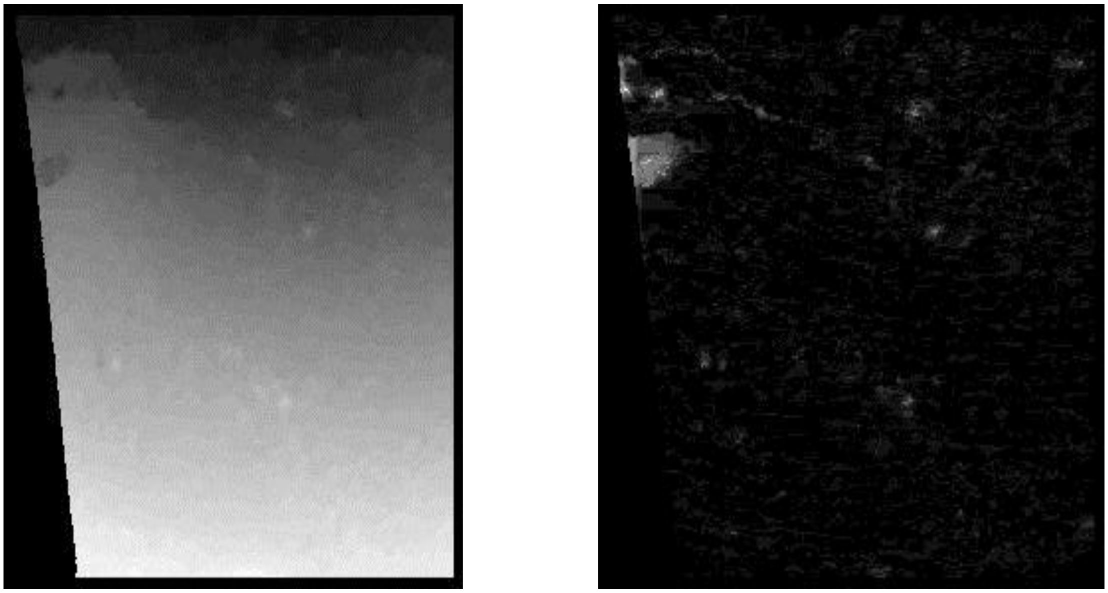
4. Matching Experiment

Because of the limitation of existing experimental site condition, in order to better evaluate the algorithm's terrain adaptability, in this paper a matching experiment is conducted by using the outdoor terrain images in image database CMU VASC, and the result is shown in Figure 2. Two algorithms for matching results of quantitative comparison are shown in Table 1, and the results of the algorithm run time comparison are shown in Table 2.

In Figure 2, Figure (a) the Left stereoscopic graphics is generated by the original image, Figure (b) is the disparity image with multi-stage method, Figure (c) is the disparity with area-matching method, and Figure (d) is about the difference of two disparity maps. The higher brightness suggests the disparity value deviation is greater in the two kinds of algorithms.

(a) Left image

(b) Disparity with multi-stage method



(c) Disparity with area-matching method (d) Difference of two disparity maps

Figure 2. The Stereo Pair "hmmwv2" and its Disparity

Figure 2 (d) shows the difference of the two disparity maps generated from the two matching methods. For the part where the difference is greater, manual inspection is conducted, and the results show that multi-stage matching method gives more accurate results. In the basic method results, the bulge stone's upper part and distant bushes part are fuzzy, but the multi-stage matching method gives an accurate description. This suggests that under the environmental conditions represented in Figure 2, the matching accuracy of multi-stage algorithm presented in this paper is improved compared to the traditional methods, and shows that the environment adaptability of the algorithm is improved.

The comparison in Table 1 shows that in the experiment illustrations more than 20% of the points take different values in the results of the two methods, and for high resolution image this value is quite big. Seen from the results, in many cases these points get together and form small areas, so it is not easy to filter out by a filter program. While the multi-stage matching algorithm can use auxiliary information of the matched point step by step to assist the following matching. Such a strategy is effective.

Table 1. Comparison of the Disparity Maps with Different Matching Methods

	Matched points shared by the two methods	disparity value different points	the points whose disparity value are greater than 1
Hmmwv1	214229	69301	9487
Hmmwv2	214157	65700	11747
Spirit-1	55203	11923	558
Spirit-2	55696	14914	1744
Spirit-3	55623	11935	639
Spirit-4	219049	61020	6962

Table 2 is the comparison of computation time with two different matching methods. It is necessary to note that it is not the main goal of this paper to improve the computing speed depending on the algorithm, despite the multi-stage matching algorithm using a variety of means to reduce the amount of computation. In addition, for most of the experimental images in order to avoid introducing distortion, stereo calibration is not conducted, so the matching search scope is not in a pixel within the line, which will affect the operation time. Therefore, meaningful data in the table is the contrast of running time of the two methods, rather than the absolute values of the running time in any kind of method. The results show the running time of multi-stage matching algorithm is less than half of the basic algorithm, which indicates that reducing the search area and other measures in multi-stage matching algorithm may play a role to reduce the amount of computation.

Table 2. Comparison of Computation Time with Two Different Matching Methods

	Hmmwv1	Hmmwv2	Spirit-1	Spirit-2	Spirit-3	Spirit-4
basic algorithm	39.48s	42.74s	10.63s	10.71s	10.67s	68.18
multi-stage matching algorithm	14.63s	14.49s	3.29s	5.01s	3.08s	18.16

5. Conclusion

Based on the speed and accuracy requirements of GPS system for vision processing, using a geometric constraint to realize a multi-stage matching algorithm, this paper introduces a matching constraint and layer-by-layer search structure which is suitable for GPS vision navigation system, and puts forward a feature aided multi-stage matching algorithm. Combining the advantages of feature matching and regional matching, the algorithm can generate more accurate and intensive disparity diagram, and has improved the matching speed and accuracy. Using different types of outdoor natural topographic map matching experiments were conducted. The experiment result shows that in matching accuracy and speed the multi-stage matching algorithm introduced in this paper is better than the basic area matching algorithm.

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