A monocular vision positioning method based on topology pattern of artificial landmark

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Abstract. Image-based positioning accuracy is usually affected by image rotation and/or distortion due to the changes of the sensor orientation. In this paper, the artificial landmark is composed of color block with different shapes, and its topology pattern is composed of the number of the block shapes, colors, shape and color of each block and topological relation among the blocks, which are robust for the artificial landmark rotation and/or tilting. The positioning is based on artificial landmark pattern matching and the corresponding relation between artificial landmark and its position. In our experiments, 196 different artificial landmarks are layered on the 3 × 3M plane uniformly. There are four blocks in an artificial landmark and each block has six different shapes and four different colors. The experiment results show that the attributions of the block were calculated accurately, the topology pattern construction and recognition method for the artificial landmark are feasible, reliable and can be used in monocular vision positioning.

Keywords: Monocular vision, topology pattern, image-based positioning.

1. Introduction

Positioning is basis for autonomous navigation and usually achieved by acquiring information from sensors, among which the visual sensor has being widely used because of its trait of large information acquiring, cost-effective and versatile [1]. According to the number of the visual sensor used, visual positioning can be divided into monocular visual positioning and binocular visual positioning. For monocular visual positioning, it is impossible to get its 3D coordinates from one plane image of the object. Binocular visual positioning can get the depth information from different views of the same scene, but image parallax elimination and pattern matching are all difficult [2]. For some monocular visual positioning methods, visual sensor’s coordinates are calculated from the distance, angle measured from the images acquired by the calibrated visual sensor [3,4]. Another monocular visual positioning method builds corresponding relation between image and location firstly, and then gets the co-ordinates by recognizing the image acquired by un-calibrated visual sensors [5].
The image used in positioning which comes directly from common traffic scene is called natural landmark, and it is difficult to extract the features for its complexity and diversity. But the features of artificial landmark are more stable and more easy to process. For example, the artificial landmark used in [6] consists of two polygons, in which a corner of the outer polygon is cut and the inner polygon is rotated 45 degrees. This artificial landmark is asymmetry and can be rotated arbitrarily. The position can be estimated more precisely by using the nine corners, two groups of perpendicular lines and four groups of parallel lines in these two polygons. The artificial landmark used in [7] is a white polygon on the deep blue circle background. This artificial landmark can be detected easily for its bright color contrast. In general, the more robust and accurate the pattern is, the more complex the landmarks should be.

Vision can provide abundant, accurate and intuitive environment information, but too much information is not always good for mathematical modeling and analysis. In addition, there are many uncertain factors, such as the change of lighting, view angle and image scaling, rotation, which will disturb image comprehension and analysis. Recently, some new methods have been used to reduce or remove the adverse effects of image distortion. For example, SIFT feature and color of image were extracted and matched according to KD tree and Bhattacharyya distance in histogram[8]. Although the algorithm has a good robustness for image rotation, lighting and other interferences, its computation cost is higher. In [9], it has been proved that the topology pattern of fingerprint has the characteristics of rotation and zoom consistency. According to the topological pattern characteristics mentioned, a monocular vision positioning method based on topology pattern of artificial landmark is presented in this paper. The artificial landmark used in the paper is blocks with 6 different shapes and 4 different colors. The topology pattern of artificial landmark includes the number of the block shapes, colors, shape and color of each block, topological relation among the blocks, which has a certain uniqueness and invariance for image rotation, stretching, warping and/or other slight distortion.

The method described in this paper achieves positioning through artificial landmark topology pattern matching and the corresponding relation between the artificial landmark pattern and its coordinates. The artificial landmark image is enhanced and filtered firstly, then corners and contour of the block are extracted to get the shape and the center coordinates of the block. The topology pattern of artificial landmark is constructed based on color block attributions and topological relation among these color blocks. The topology pattern given in this paper has a certain robustness for the image rotation and/or tilting caused by the orientation changing of the visual sensor, which has a negative influence on the accuracy of positioning. Finally, some experiments were carried out and the experiment results indicate that the method given in this paper can satisfy the requirements of the mobile robot positioning.

2. Artificial Landmark and its Attribution Calculation

In general, the artificial landmark is more complex, its uniqueness is better, while the processing and recognition of complex landmark is more difficult. A simple and unique artificial landmark was presented in this paper, there are four color blocks in the artificial landmark, the color of the block is one of red, yellow, cyan1 and green, the shape of the block is one of circle, square, regular triangle, regular pentagon, regular hexagon and five-pointed star. In this monocular visual positioning based on topology pattern of artificial landmark, the corresponding relation between artificial landmark topology pattern and its coordinates should be ensured firstly, then the positioning is achieved by artificial landmark recognition.

The process of monocular visual positioning based on artificial landmark topology pattern matching includes preprocessing, color and shape calculation, topological relation among color blocks calculation and topology pattern structuring and matching, which can be described as Fig.1.
In order to reduce the influence of lighting and/or others, the artificial landmark image should be pre-processed before the block attributions are extracted. Firstly, the image was binary processed in RGB channels respectively with adaptive thresholds. Green and cyan blocks are left in R channel image, red block is left in G channel image, red, yellow and green blocks are left in B channel image. Then enhanced images in RGB channels are merged together as Fig. 2a, it can be seen that the image background is white, the edge and colour of block are more distinct. Meanwhile, as shown in Fig. 2b and 2c, fissure, spot and other noises are all cleared out. These consequences indicate that the method of image pre-processing given above is preferable, which can satisfy the requirement in the following block attribution extraction.

**Fig.1 Artificial landmark processing and topology pattern construction**

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**Fig.2 Artificial landmark colourful image processing**

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Generally, image edge detection algorithm is based on its first and/or second order derivation operator such as Sobel, Robert, Laplace and Canny operator. The first order operator cannot find the boundary of the image with uniform gray and the second order operator is sensitive to noise that should be removed away before[10]. The Canny edge detector is an edge detection operator using a multi-stage algorithm to detect a wide range of edges in images that is used in this paper[11]. The color artificial landmark image is transformed to a gray image using the following formula firstly:

\[
\text{Gray value} = 0.299*R + 0.587*G + 0.114*B
\]

(1)

In addition, the following Gaussian filter is used to smooth the transformed gray artificial landmark image to reduce the influence of noises with 3x3-kernel mask:

\[
G_y = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2 + y^2}{2\sigma^2}}
\]

(2)

Where \(\sigma = (ksize/2 - 1) \times 0.3 + 0.8,\) and ksize = 3. Then the intensity gradients and the direction of the image are calculated out, non-maximum suppression is used to get rid of spurious in edge detection. If the gradient of a certain pixel is more than th2, the pixel belongs to contour pixel. Moreover, in an 8 neighborhood of a pixel, if the gradient of any pixel is greater than th1, the pixel is contour pixel too (th1=30, th2=100 here). Fig.3b is edge detection result of Fig.3a.

The contour of the integrated block should be a closed curve, but there always exists some unclosed contours at the edge of the artificial landmark image. The broken block has a negative impact on feature
extraction and should be removed. Firstly, every contour is marked if any part of the contour lays in the image borders. Then all the marked contours are traversed successively and the contour should be eliminated if it is unclosed. Fig. 3c is broken contour eliminating result of Fig. 3b.

![Image of original, Canny edge detection, and edge broken contour elimination.](image)

**Fig. 3** Elimination of broken contour

The block shape is determined based on contour and the number of corners. There are many methods can be used to acquire corners in a gray image such as Moravec, SUSAN and Harris. Moravec is one of the earliest corner detection algorithms, in which a point with low self-similarity is called corner. The algorithm extracts the corner from the image by considering how similar a patch with a corner at its center and its nearby patches are. The similarity is measured by summing the squared differences between the corresponding pixels of two patches and lower value indicates more similarity. One of the main problems of this operator is that it is not isotropic [12]. In Harris arithmetic, if a certain window moving in any direction leads to obvious change of the sum of the pixel grey value in it, the center pixel of this window is corner.

Define:

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_xI_y \\ I_yI_x & I_y^2 \end{bmatrix}$$

(3)

Let:

$$R = \det M - k(\text{trace}M)^2 \quad k \in [0.04, 0.06]$$

(4)

where $w(x,y)$ is window function, $I(x,y)$ is the image intensity, and $I_x$, $I_y$ are partial derivatives of $I(x,y)$ in $x$, $y$ direction. Suppose the two eigenvalues of $M$ are $\lambda_1$, $\lambda_2$, so $\det M = \lambda_1\lambda_2$, $\text{trace}M = \lambda_1 + \lambda_2$. The center of corresponding window is corner when $R$ is greater than a threshold. Harris algorithm has rotation invariance and affine invariance, but it does not have scale invariance[13]. Shi-Tomasi algorithm has improved based on Harris and is adopted in this paper to extract the block corner, in which if the smaller eigenvalue of $M$ is more than a threshold, the corresponding pixel is corner[14].

From block shape of artificial landmark, it can be seen that the number of corners on a closed contour are 0, 3, 4, 5, 6 and 10 respectively. If there exist other number of corners, it states that some fake corners were collected and should be eliminated. According to the geometrical relation between the three adjacent corners, if the smaller included angle of two lines which connected two adjacent corners is less than a threshold, these three corners can be concern on the same line, and the middle corner can be regarded as pseudo corner. In this paper, the threshold is 35 degrees. The pseudo corner was eliminated using the above method by traversing all the corners in a closed contour. And if the number of corner in a contour is less than 3, the contour can be regarded as circle. Fig. 4a is original image of artificial landmark, Fig. 4b is the result of contour detection, and Fig. 4c is the corner extraction result of Fig. 4b, in which there exists multiple pseudo corners in two quadrangles. Figure 4d is the pseudo corner elimination result of Fig. 4c, from which it can be seen that the pseudo corners were completely eliminated in quadrangle.
In order to keep the images consistence on the same scene, vertical distance between visual sensor and the flat of artificial landmark should be keep constant and the optic axis of the visual sensor should be vertical to the flat. In fact, artificial landmark image might be rotated because of visual sensor rotation or other reasons as shown in Figure 5a. The artificial landmark contours and corner detecting result of Fig. 5a, Fig. 5c is Fig. 5b, Fig. 5d respectively. From Fig. 5b, Fig. 5d it can be seen that the number of block corners is correct and contours are closed. More rotated and/or distorted artificial landmark images were used to test the algorithm given above, all of the corner extraction are all correct and all of the block contours are closed, which indicate that the method of artificial landmark pre-processing, block contours and corner extraction given are reliable and robust.

In this paper, there are circle, regular triangle, square, regular pentagon, regular hexagon and five-point star, where there is no corner on circle, and the number of corners of other block is 3, 4, 5, 6 and 10 respectively. The center coordinates of block are calculated by mean of the corner coordinates in every block. Nevertheless, the center coordinates of a circle are calculated by all pixels coordinates on the contour because there is no corner on the circle. Figure 6 shows a result of center computing of every block in the artificial landmark image

In this paper, there are red, yellow, green and cyan1 for the artificial landmark block, and block color is determined by the center pixel of color block and its 8 neighbor pixels. The mean of the 9 pixels in RGB are calculated respectively, and the color is ensured by the following formula:
3. Artificial Landmark Pattern Construction and Matching

Usually, there is more than one artificial landmark pattern in an image collected by the visual sensor, and the main pattern of the image should be confirmed after the color block shape and color were ensured. In this paper, there are 4 blocks in an artificial landmark pattern and it is assured that the farthest distance among blocks in a same pattern is less than minimum distance among blocks in different pattern, and the latter is 1.5~2 times long as the former. The distance between two color blocks is defined as the distance between the centers of these two blocks, the block with its other 3 nearest blocks formed a pattern together and the pattern center is defined as the center of these 4 blocks. For an image, the main pattern is the topology pattern of artificial landmark, which is the nearest one to the image center.

The topology pattern of the artificial landmark is made up of the number of block shapes and colors, the shape and color of each block, topological relation among the 4 color blocks. In this paper, the relative position relation among color blocks is used to describe the topological relation of the blocks. In the topology pattern of artificial landmark, the 4 color blocks are arranged into an anticlockwise circle as shown in Fig.7, which has the characteristics of rotation and zoom consistency. A rectangular coordinate system with the center of 4 color blocks as the original point divides the plane into four parts, the first part is defined as the first quadrant and y positive axis, the second part is defined as the second quadrant and x negative axis, and so on. The anticlockwise circle begins from the block located in the first part, and then the block located in the second part, and so on. If there are more than one block located in the same part, the order in the circle is the ascent order of included angle of the x positive axis and the line between the origin of the coordinate system and the center of the blocks.

Artificial landmark topology pattern can be described as:

$$X = \{C_{Num}, S_{Num}, (C, S) | i = 1, 2, 3, 4\}$$

Where CNum, SNum is the number of color and shape of all blocks in the artificial landmark respectively. C is the block color and 1, 2, 3, 4 are used to denote red, yellow, cyan1 and green respectively. S is the number of block corners and 0, 3, 4, 5, 6, 10 are used to represent circle, regular triangle, square, regular pentagon, regular hexagon and five-point star respectively. (C, S) sequence is
anticlockwise order sequence of the 4 blocks in the circle, which represents the topological relation among the 4 blocks.

For two topology patterns of the artificial landmark:

\[ X_1 = \{ CNum_i, SNum_i, (C_i, S_i) \mid i = 0,1,2,3 \} \]  \hspace{1cm} (7)

\[ X_2 = \{ CNum_j, SNum_j, (C_j, S_j) \mid i = 0,1,2,3 \} \]  \hspace{1cm} (8)

Define:

\[ D_k = \sum_{i=0}^{3} \left[ (C_{1,i} - C_{2,(i+k) \% 4})^2 + (S_{1,i} - S_{2,(i+k) \% 4})^2 \right] \quad k = 0,1,2,3 \]  \hspace{1cm} (9)

The number of colours and shapes of blocks in two patterns were compared firstly to reduce the number of matched pattern and improve the matching efficiency. If and only if \( CNum_1 = CNum_2 \) and \( SNum_1 = SNum_2 \), the difference between two patterns \( D_k \) were calculated. If \( D_k = 0 \), it means that the two patterns is matched.

4. Experiments and Results Analysis

In order to verify the effectiveness and reliability of the monocular visual positioning method given, the following experiments were carried out.

Experiment 1: 196 artificial landmarks are laid on the 3m*3m plane with 20cm*20cm interval. The diameter of the circumcircle of the colour block is 5cm. 100 artificial landmark images were randomly acquired, in which 998 valid blocks are left after pre-processing. In these 998 blocks, only 1 block shape is not right, which shows that the method of block attribution extraction presented in this paper can satisfy the requirements of artificial landmark topology pattern construction. The attributions of every block in Fig.2a are shown in Table 1.

| Centre coordinate | Corner numbers | Shape       | Colour  |
|-------------------|----------------|-------------|---------|
| (356,343)         | 4              | square      | red     |
| (110,216)         | 4              | square      | green   |
| (191, 212)        | 5              | regular pentagon | cyan1   |
| (429,213)         | 0              | circle      | red     |
| (349, 209)        | 6              | regular hexagon | yellow |
| (101,139)         | 3              | triangle    | yellow  |
| (188,136)         | 4              | square      | red     |
| (420,129)         | 3              | regular triangle | green |
| (348,124)         | 10             | five-point star | cyan1   |

Experiment 2: In order to verify the feasibility and reliability of artificial landmark topology pattern construction and recognition methods. 100 images were collected randomly by monocular visual sensor. After the pre-processing and the block shape, colour extraction, the main artificial landmark pattern was determined. The topology pattern of the artificial landmark was constructed and matched.

There are 99 patterns matched correctly but only 1 pattern was mismatched for the reason that the property of block in the artificial landmark acquired was not right. Nevertheless, in the 99 right matched patterns, there existed a wrong positioning because of wrong matching.

The positioning accuracy of the method given is related to the number of artificial landmark patterns, the more artificial landmark patterns in unit area, the higher positioning accuracy can be achieved. According to the number of block colour, shapes and the topological relation among the 4 colour blocks, there are total 82944 different patterns of the artificial landmark designed in this paper. In order to improve the matching efficiency, a faster slice matching strategy was adopted. The whole patterns were divided into 16 sections in advance according to the number of block colour and shapes.
During the pattern matching, the matching section was filtered according the number of block colour and shapes, and the pattern was matched with the patterns in the selected section to reduce the matching time. For the reason that the moving scope is limited, it need not to compare the artificial landmark topology pattern with all the patterns in the section, but only with its neighbour patterns, which can improve matching efficiency and reduce matching error.

In the faster slice matching strategy, the pre-stored pattern has been classified according to the number of block colour and shapes, so the corresponding pre-stored patterns were less than the patterns in general matching. The faster slice matching strategy is about 6 times faster than the general matching strategy. For matching without data reading, the faster slice matching strategy is about 2 times faster than the general matching strategy as shown in Table 2.

| Pattern No | Matching and data reading/ Only matching | Fast slice matching (s) |
|------------|-----------------------------------------|------------------------|
|            | General matching(s)                     |                        |
| 0          | 2.022/0.038                             | 0.133/0.013            |
| 1          | 2.016/0.031                             | 0.063/0.005            |
| 2          | 2.016/0.032                             | 0.656/0.026            |
| 3          | 2.000/0.031                             | 0.673/0.011            |
| 4          | 2.024/0.056                             | 0.213/0.015            |
| 5          | 1.985/0.016                             | 0.391/0.010            |
| 6          | 2.051/0.067                             | 0.133/0.018            |
| 7          | 2.016/0.047                             | 0.653/0.043            |
| 8          | 2.000/0.016                             | 0.195/0.010            |
| 9          | 2.015/0.015                             | 0.118/0.005            |
| mean       | 2.015/0.035                             | 0.323/0.016            |

5. Summary
This paper constructs artificial landmark by using color block, establishes corresponding relation between artificial landmark and its location, acquires image by monocular visual sensor and achieves positioning after image preprocessing, block shape and color acquiring, main artificial landmark pattern ensuring, artificial landmark topology pattern constructing and matching. The artificial landmark topology pattern adopted in the paper is robustness for artificial landmark image translation, rotation and affine transformation. The artificial landmark topology pattern unmatched or mismatched mostly because of the wrong color block properties. The positioning accuracy of the method given in this paper is related to the number of artificial landmark patterns, the more artificial landmark patterns in unit area, the higher positioning accuracy can be obtained. In general, the results of the experiments indicate that the method given in this paper is available, feasible and reliable. In order to improve reliability and effectiveness of monocular visual positioning based on the topology pattern of artificial landmark, the calculating method of block shape and color, the faster method of artificial landmark topology pattern constructing and matching should be further studied.

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