한국정보전자통신기술학회논문지(jkiiect)'20-2, Vol.13 No.1
논문 20-13-01-58 http://dx.doi.org/10.17661/jkiiect.2020.13.1.58

Generation of Feature Map for Improving Localization of Mobile Robot based on Stereo Camera

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스테레오 카메라 기반 모바일 로봇의 위치 추정 향상을 위한 특징맵 생성

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Abstract This paper proposes the method for improving the localization accuracy of the mobile robot based on the stereo camera. To restore the position information from stereo images obtained by the stereo camera, the corresponding point which corresponds to one pixel on the left image should be found on the right image. For this, there is the general method to search for corresponding point by calculating the similarity of pixel with pixels on the epipolar line. However, there are some disadvantages because all pixels on the epipolar line should be calculated and the similarity is calculated by only pixel value like RGB color space. To make up for this weak point, this paper implements the method to search for the corresponding point simply by calculating the gap of x-coordinate when the feature points, which are extracted by feature extraction and matched by feature matching method, are a pair and located on the same y-coordinate on the left/right image. In addition, the proposed method tries to preserve the number of feature points as much as possible by finding the corresponding points through the conventional algorithm in case of unmatched features. Because the number of the feature points has effect on the accuracy of the localization. The position of the mobile robot is compensated based on 3-D coordinates of the features which are restored by the feature points and corresponding points. As experimental results, by the proposed method, the number of the feature points are increased for compensating the position and the position of the mobile robot can be compensated more than only feature extraction.

요 약 본 논문은 스테레오 카메라를 이용한 모바일 로봇의 위치 추정 정확도 향상을 위한 방법을 제안한다. 스테레오 카메라로 획득한 스테레오 이미지로부터 위치 정보를 복원하기 위해서는 왼쪽 영상의 각 픽셀에 대응하는 대응점을 오른쪽 영상에서 찾아야 한다. 일반적으로 에피폴라 라인 위의 점들과 픽셀 유사도를 연산하여 대응점을 찾는 방법이 있다. 하지만 모든 에피폴라 라인 위의 점들을 다 탐색해야한다는 단점이 있고, 픽셀 값에 의해서만 유사도가 계산된다는 단점이 있다. 이를 보완하기 위해 본 논문에서는 좌/우 영상의 특징점을 추출 및 매칭하여 대응하는 점들이 같은 y축 상에 있을 경우, x좌표 값의 차를 구함으로 대응점 탐색방법을 간략하게 구현하였다. 또한 매칭이 되지 않아 소실되는 점들의 정보는 기존 알고리즘을 통해 대응점을 구함으로 특징점 수를 최대한 보존하고자 하였다. 특징점 및 대응점의 좌표를 통해 복원된 특징점의 3D 좌표를 기반으로 모바일 로봇의 위치를 보정하였다. 실험 결과, 제안하는 방법을 통해 좌표 보정을 위한 특징점 수를 증가시켰고, 특징점 추출만 수행한 경우보다 모바일 로봇의 위치도 보정 가능함을 확인하였다.

Key Words : Disparity Map, Feature Extraction, Localization, Stereo Camera, Stereo Matching

This research was supported by BK21PLUS, Creative Human Resource Development Program for IT Convergence and was supported by the Technology Innovation Program(10073147, Development of Robot Manipulation Technology by Using Artificial Intelligence) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea) and was funded and conducted under 『 the Competency Development Program for Industry Specialists 』 of the Korean Ministry of Trade, Industry and Energy (MOTIE), operated by Korea Institute for Advancement of Technology (KIAT). (No. P0008473, The development of high skilled and innovative manpower to lead the Innovation based on Robot).
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Received January 20, 2020 Revised February 13, 2020 Accepted February 17, 2020

1. Introduction

Autonomous Guided Vehicle (AGV) can load and unload the cargo automatically. It is generally applied in various industrial fields. Because it can operate twenty-four hours a day unlike human. Also, it can reduce labor cost and prevent loss of lives. To control driving of the mobile robot like AGV, sensors are used such as magnetic, laser navigation, vision sensor, and so on. Among these sensors, vision sensor is used because it is similar with human's eyes. It can contain numerous data in the image. Especially, stereo camera can restore the 3D coordinate like human's eyes. So, we consider the stereo camera for controlling of the mobile robot.

To restore the 3D information from stereo images, the corresponding pixel should be found. Because the gap of the pixel and the corresponding pixel is related to 3D information. In this paper, to search for the corresponding point, the feature matching method can be applied. Extracted features have an effect on the localization accuracy because they have marked features. However, when the feature matching algorithm is applied, some features, which are not matched, are excluded from the data which will be used for the localization. Therefore, this paper proposed the method which uses all extracted features. To implement this concept, block matching is applied with respect to unmatched features.

2. System Configuration

The mobile robot has the driving system of differential wheeled type. Two encoders are included in motor drivers. Encoder is used for localizing the mobile robot. However, when only encoders calculate the position of the mobile robot, the localization error is high. Because the process of the position calculation generates the cumulative error. Therefore, we compensate the position of the mobile robot by using the position calculated from the vision sensor.

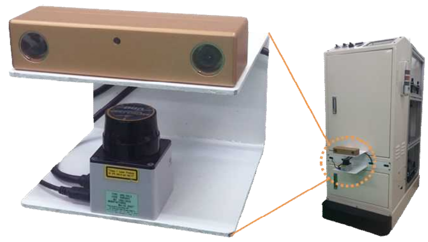


Fig. 1. Designed mobile robot

The mobile robot based on vision sensor was designed as shown in Fig. 1. In front of the mobile robot, Bumblebee2 is mounted. It acquires the scene to localize the mobile robot by compensating the position of the mobile robot calculated by encoder.

3. Proposed Method

3.1 Overview

This paper proposes the method for improving the accuracy of the localization of the mobile robot. The overview process of the proposed method is shown in Fig. 2.

The position of the mobile robot is calculated by only encoder until acquiring the images from stereo camera like process 1 in Fig. 2. When the images are acquired, process 2 is conducted. To localize the mobile robot based on vision sensor, there are three parts in the proposed method:

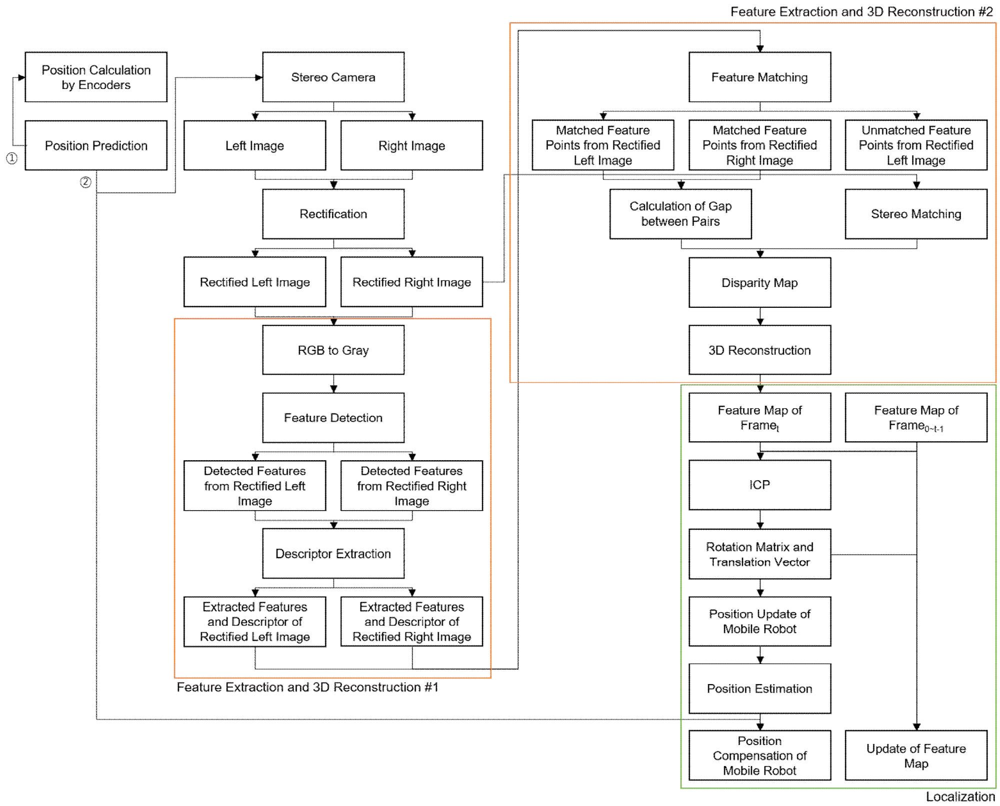


Fig. 2. Overview of the proposed method

feature extraction and matching, 3D reconstruction, and localization.

Images acquired from stereo camera should go through image pre-processing step such as rectification and gray-scale transformation. And then, feature detection and descriptor extraction are conducted for generating the disparity map which is related to depth value. To improve the accuracy of the localization, we also use unmatched feature points for generating the disparity map by stereo matching. Disparity map which is generated by matched features and unmatched features is reconstructed as xyz coordinate system. After 3D reconstruction, the rotation matrix and translation vector related to feature map of framet and feature map of frame0~t-1 are calculated by using Iterative Closest Point (ICP) algorithm. And, feature map of framet and feature map of frame0~t-1 are combined. Finally, the position of the mobile robot is compensated.

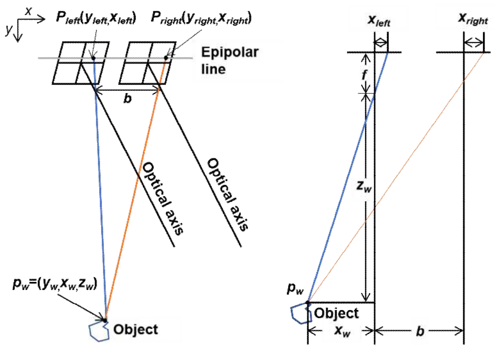


Fig. 3. Geometry of stereo vision: projection process and simplification to 1D

3.2 Feature Extraction and 3D Reconstruction

As aforementioned, 3D information can be restored from stereo images. To restore depth information, we should search for corresponding point. Because depth information is calculated by the gap of one pixel and corresponding pixel. However, it is inefficient to calculate all pixels of the image for finding the corresponding point. So, we align the images by the rectification. Through the rectification, the corresponding point is located on the epipolar line. Therefore, we search for the corresponding point on the epipolar line instead of all points.

Fig. 3 shows the geometry of the stereo vision. First, left image represents the projection process. After the rectification by using camera parameter, the corresponding point is located on the epipolar line. Right image denotes the simplification to 1D. By using Eqs. (1)~(3), the depth information can be calculated [1].

$$\frac{x_{left}}{f} = \frac{x_w}{z_w} \tag{1}$$

$$\frac{x_{right}}{f} = \frac{b + x_w}{z_w} \tag{2}$$

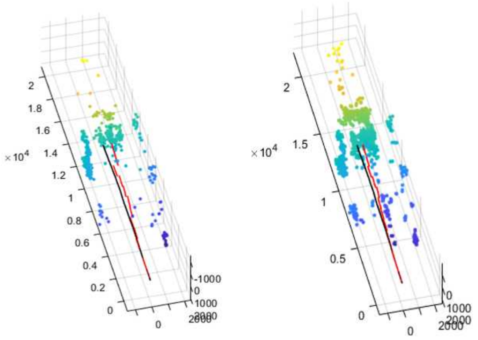
$$z_w = \frac{bf}{x_{right} - x_{left}} = \frac{bf}{d} \tag{3}$$

However, this paper proposes the method to search for the corresponding point by using the feature extraction and matching. Because the corresponding point is already located on the epipolar line, if we match features, the depth information can be calculated efficiently.

The reduction of the feature points occurs after the step of feature matching algorithm, because the unmatched features are excluded in 3D reconstruction. To make up for this weak point, the corresponding points of unmatched features are calculated by block matching. This leads to increase the 3D feature information and improve the accuracy of the localization of the mobile robot. And, we calculate the rotation matrix and translation vector by using ICP and 3D feature information [2-4].

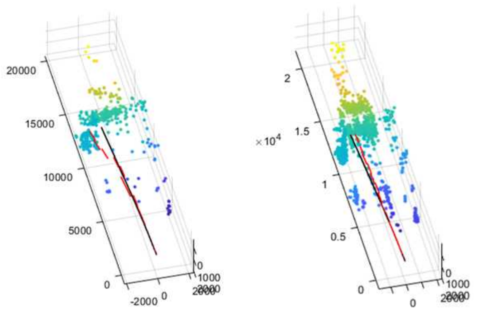
3.3 Localization

To calculate the position of the mobile robot, the encoder data are used. However, they generate the cumulative error. To compensate the position of the mobile robot, we used the stereo images. To combine the encoder data and stereo images, Extended Kalman Filter (EKF) is applied [5]. EKF consists of a predictor-corrector algorithm. In this paper, state vector represents the position of the mobile robot. This value is calculated by kinematics from encoder data. Measurement value denotes coordinates of feature points



(a) (b)

Fig. 4. Extracted features and result of localization – Experiments #1: (a) feature matching, (b) proposed method



(a) (b)

Fig. 5. Extracted features and result of localization – Experiments #3: (a) feature matching, (b) proposed method

by the stereo images. Through EKF algorithm, the position calculated by stereo images is used for compensating the position calculated by kinematics. The compensated position is updated as the position of the current frame, and it can improve the localization accuracy.

4. Experimental Results

To verify the proposed method, we compared the error in case of the position calculated by encoder, only feature matching, the proposed method. The reference data are the localization data from Stargazer which is mounted on the designed mobile robot. Figs. 4 and 5 show that the extracted features and the result of the localization in case of the only feature matching and the proposed method. The black line is the localization result by encoder. The red line is the localization

Table 1. Experimental results

	Error		Encoder	Feature Matching	Proposed Method
1	Distance	Average	669	235	205
		Max	903	592	447
		RMSE	200	83	70
	Angle	Average	−3	−2	−1
		Max	1	1	0
		RMSE	1	1	1
2	Distance	Average	269	234	176
		Max	617	928	505
		RMSE	92	107	68
	Angle	Average	−3	1	−2
		Max	0	9	1
		RMSE	1	1	1
3	Distance	Average	335	363	114
		Max	652	1187	213
		RMSE	110	151	38
	Angle	Average	−2	4	2
		Max	2	11	3
		RMSE	1	2	1
4	Distance	Average	406	316	245
		Max	1434	1246	1740
		RMSE	150	131	143
	Angle	Average	−3	−2	2
		Max	0	2	7
		RMSE	1	1	1
5	Distance	Average	201	233	204
		Max	548	530	520
		RMSE	74	83	78
	Angle	Average	−3	−3	−2
		Max	0	0	0
		RMSE	1	1	1

Table 2. Comparison of the number of feature points

Experiments	Feature Matching	Proposed Method
1	480	3562
2	456	3242
3	511	3393
4	420	2708
5	387	2500

result by feature matching and the proposed method. By the proposed method, the features for the localization are increased and the position is compensated.

The five experiments were performed by driving in a straight line. The experimental result about the error is shown in Table 1. Average and max are the average value and the max value of the error. RMSE is the value of the root mean square error.

As shown in the table, compared with the other two cases, the proposed method can reduce the error. The number of the feature points by the proposed method is about 6~7 times more than the case by only feature matching as shown in Table 2.

5. Conclusions

This paper proposes the method to improve the accuracy of the position of the mobile robot. To implement this purpose, the feature extraction, block matching and EKF are applied. Based on experimental results, the proposed method can improve the localization accuracy and preserve the number of feature points. In the future work, the relationship of the feature points is considered for the localization.

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