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Application of SLAM in the biomedical field

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Abstract. With the continuous development and improvement of sensors, sensor technology is also constantly making breakthroughs. It is also widely used in various fields of medicine today. This article summarizes the practice of two types of SLAM (Simultaneous Localization and Mapping) in medicine. The detection and matching of human luminal feature points under SLAM were studied so as to reconstruct the human internal environment so that doctors can obtain three-dimensional reconstruction feedback within the surgical range and improve the safety of surgery. And for different surgical environments, the same SLAM is improved on the basis of innovation, which is more suitable for different scenarios. Three algorithms are described in this article for taking images of the inside of the abdominal cavity and collecting data based on the images using different algorithms. Based on the collected data, the internal abdominal cavity is reconstructed in 3D. Finally, a three-dimensional visualization system for the abdominal cavity was constructed. It has important research significance in the field of medical auxiliary research.

Keywords: SLAM; biomedicine; three-dimensional reconstruction.

1. Introduction

SLAM is mainly used to solve the problem of positioning map construction when mobile robots are running in unknown environments, that is, to build a map and simultaneously locate the robot in the map.

The hardware components of a typical SLAM system are mainly ranging sensors, odometry odometers, motion robots, etc. The process includes feature extraction, data association, state estimation, and status update.

SLAM can be divided into visual SLAM and laser SLAM according to sensors. Visual SLAM is based on the image information returned by the camera, and laser SLAM is based on the point cloud information returned by the lidar. The workflow for the Vision SLAM is shown in Figure 1.

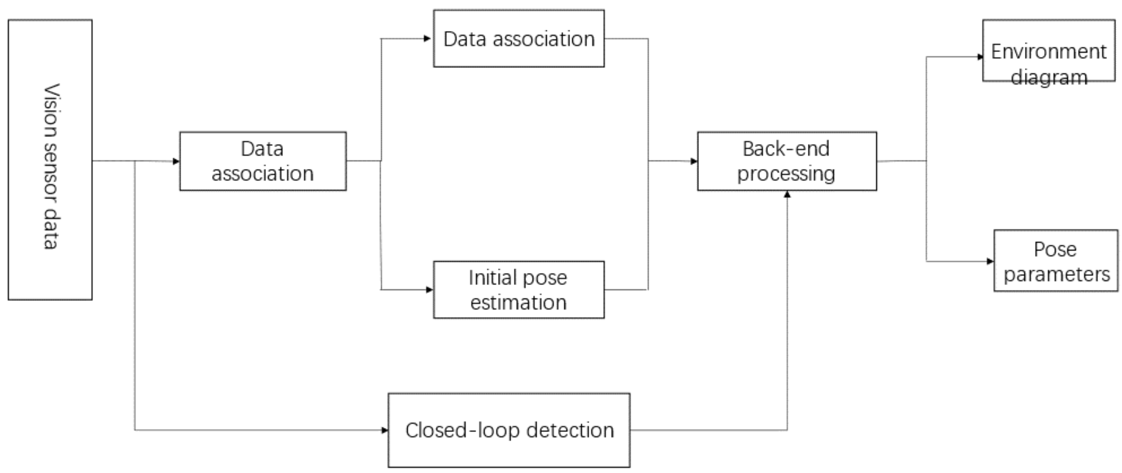

Figure 1. Schematic diagram of visual SLAM.

Visual SLAM technology was originally the most robotic hotspot technology that was proposed in the 80s of last century, used to complete the two main tasks of locating mobile devices and reconstructing the surrounding environment map. In recent years, the advanced SLAM algorithm has been based on image features. In the natural scene, assuming that the lighting is unchanged and the object meets the rigidity requirements, the use of visual SLAM for positioning tracking and map reconstruction has entered a mature period. In 2021, Yubao Liu et al. proposed the RDS-SLAM system, which is a real-time dynamic SLAM algorithm based on ORB-SLAM [1][2]. In 2012, Visentini et al. proposed to restore the three-dimensional structure of the gastrointestinal tract by SFS, (Shape from Shading) and proposed a calibration method [3]. In 2014, Noohi et al. proposed a monocular visual method to reconstruct a deformed liver [4]. In 2015, Yang et al. proposed an SFM (Structure from Motion) based on the transmission of data by a six-degree-of-freedom tracking sensor [5]. In 2018, Turan et al. used a combination of SFS algorithm and SFM algorithm to construct gastrointestinal surfaces by module classification [6]. In 2021, Li et al. proposed depth and motor estimation based on monocular vision based on unsupervised learning [7].

With the accumulation of errors in the mapping process, the monocular vision method cannot form a real closed loop, and there is a problem of map drift. Since the monocular vision method needs to use the correct matching relationship between the inner cavity images to complete the high-precision reconstruction, SLAM technology effectively solves the cumulative error in the construction of the inner cavity closed-loop map, which has the advantage of complete map construction and is widely used in the scene of internal cavity image map reconstruction, with good development prospects.

2. Medical applications of SLAM

In the study of Wang Ying et al. in 2021, the detection and method of feature points in the three-dimensional reconstruction of SLAM human lumen were studied [8]. In this study, a forward-looking odometer module of the SLAM framework was implemented. Considering the unique characteristics of human cavity images, to achieve targeted preprocessing of cavity images, the detection matching of a group of feature points was studied. Firstly, based on the particularity of the human body, Hamlyn and pelvic medical datasets were used to study the luminal image execution wallpaper based on highlight detection and highlight repair. Secondly, the feature points in the human cavity are detected and matched; The vascular branch point was the main detection table, and the CDVB algorithm was used to

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detect the branch point. The special texture structure of the inner cavity was used to carry out block matching based on feature points, and the line matching based on vascular lines was studied. Set the repetition rate and efficiency as indicators for feature point detection and matching, and complete the horizontal comparison. Finally, the SLAM framework visualization odometer module is implemented in the body cavity environment, and the three-dimensional reconstruction model of the body cavity is obtained.

2.1. Preprocessing of human viscaval images

In this study, highlight detection and highlight restoration were used. Firstly, the colour characteristics of the highlight are used to detect the absolute highlight area, and the relative highlight region of the lumen image is detected by median filtering. Highlight repair based on replacing highlight pixels and smooth Gaussian kernel function filtering suppresses highlight areas on the image. The single green channel is used to grayscale the image after specular suppression, and the Hessian matrix is used to extract the image information in the image [9]. In order to improve the accuracy of subsequent feature point detection, the blood vessels are single-pixelated by finding the first-order differential symbol jump point of the grey pixel value on the feature vector, and finally, the single-pixel width blood vessel image is obtained. The workflow diagram of this chapter is shown in Figure 2.

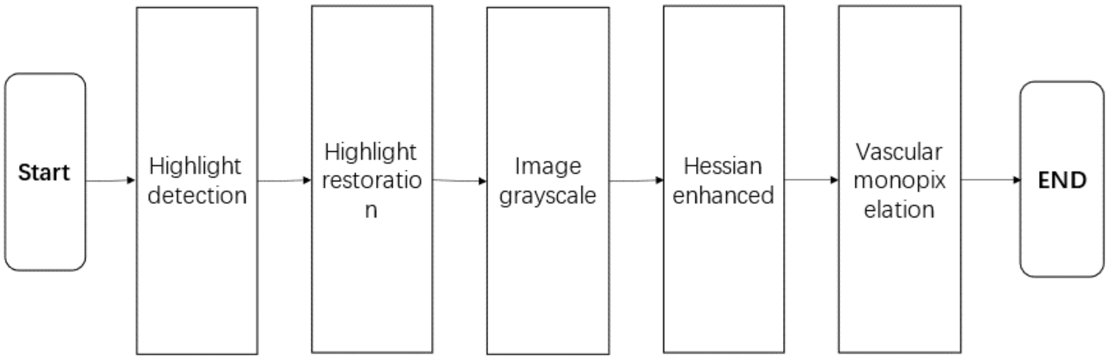

Figure 2. Flow chart of lumen image preprocessing [8].

2.2. Human luminal feature point detection and matching

According to the vascular texture characteristics of the luminal image, the vascular divergence point was selected as the main feature detection target, and the extraction method was carried out with the candidate point as the original review. The FAST (Features from Accelerated Segment Test) algorithm supplements the original detected feature points and increases the density of feature points [10]. To completely remove the bright pixels of the image, the FAST algorithm improves the algorithm formula instead of maximum suppression to obtain the most efficient feature point detection results.

2.3. SLAM-based three-dimensional reconstruction of human lumen

In this part, using the results of the previous two parts, SLAM's 2D-2D feature point algorithm is used to realize the point cloud connection, and according to the key frame information, more complete point cloud data in the human body can be obtained. Using Poisson surfaces to reassemble points into smooth surfaces, texture them, and obtain three-dimensional restoration results inside the human body. The flowchart of this chapter is shown in Figure 3.

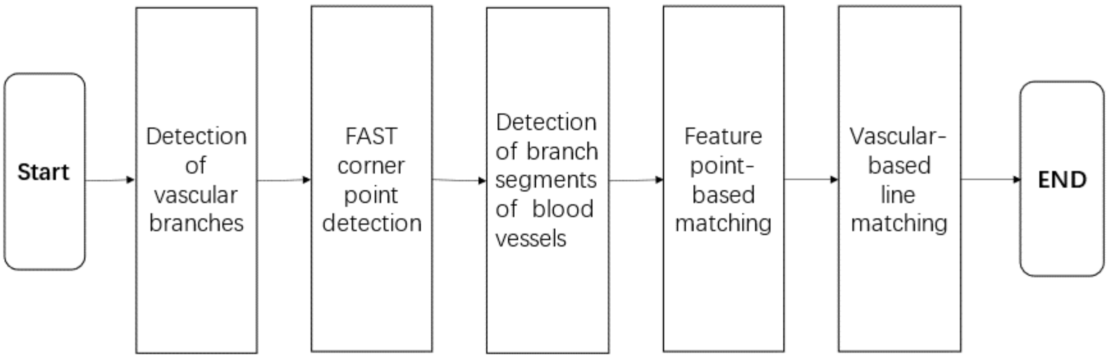

Figure 3. Flow chart of feature points detection and matching in lumen [8].

3. Study of SLAM methods in minimally invasive surgery

In 2022, Zhang Tao studied SLAM methods in minimally invasive surgery. In this study, the shortcomings and disadvantages of traditional minimally invasive surgery are discussed, and the existing problems in traditional minimally invasive surgery that can be solved by reusing visual SLAM technology are discussed.

3.1. Feature extraction and matching design based on Superpoint algorithm

The Superpoint algorithm combined with the aggregation algorithm is used for feature extraction and matching, which has good results in the complex environment of the lumen. Firstly, the combination of the clustering algorithm and Superpoint algorithm is used to extract feature information, and secondly, the RANSAC algorithm is used to remove false matching. The results show that the improved algorithm consumes the shortest time to extract image features, the largest number of successful matches, and the lowest false matching rate. Feature point detection combined with deep learning has obvious advantages over traditional extraction methods.

3.2. Estimation and optimization of endoscopes

The position and attitude information of the endoscope during surgery were solved by the offence, and the least squares problem was constructed for optimization. Since the true position of the endoscope is not provided in the endocavity image, by verifying the effectiveness of the algorithm by providing the public data set of the real position, the accuracy of the Bundle Adjustment algorithm in estimating the rotation matrix and translation vector of the endoscope is verified according to the feature point mapping results in the image of the endoluminal environment.

3.3. Three-dimensional reconstruction of endoscopic images

Firstly, the difference in the target area is obtained by the stereo-matching method and optimized. Secondly, the parallax value is used to calculate the depth to form a deep image; Finally, the three-dimensional point cloud data is further calculated.

4. Understanding and application of specific algorithms

4.1. SIFT (Scale-Invariant Feature Transform) algorithm

In the visual SLAM employed in minimally invasive surgery, the SIFT algorithm can be used to extract image feature points. The algorithm mainly has the following steps for image processing:

(1) First, the scale parameter is introduced, the spatial sequence of the scale space is constructed to obtain, and the contour is extracted as the image feature vector.

(2) After the initial detection of image feature points, further precise point location information is required.

(3) Assign and align the direction of the key point, obtain the distribution characteristics of the pixel gradient and direction in the acquisition field, and take the direction of the maximum histogram as the main direction of the key point to ensure the invariance of rotation.

(4) To establish a descriptor for the extracted stable feature point, the corresponding feature point can be found through the descriptor.

4.2. SURF (Speeded-Up Robust Features) algorithm

The SURF algorithm is an improved algorithm for the SIFT algorithm, and its improvement mainly lies in the following:

(1) After extracting the feature points, the Hessian matrix is used to approximate the image, and the maximum local value is obtained in the discriminant formula of the matrix, and then the key points of the image are located under this condition to determine whether the image has highlight pixels.

(2) Before constructing the Hessian matrix, the image is preprocessed using a cassette filter. When constructing the scale pyramid of the image, only the size of the box filter is changed so as to ensure the scale invariance of the feature points.

(3) Use the Hal wavelet transform to calculate the key cardinal direction.

Through similar ideas, the SUFR algorithm simplifies the filtering to a certain extent, and its operating speed is accelerated by about three times since SIFT, which improves the acquisition efficiency of feature points.

4.3. K-Means clustering algorithm

The algorithm is to treat all the data, randomly select K points in the whole, and these points are the initial cluster centre, divide other data into the centre with the smallest Euclidean distance, recalculate the distance between each data cluster point, take the average and recalculate the cluster centre for a new round of data cluster division, until the clustering result remains unchanged or reaches the preset maximum number of iterations.

5. Conclusion

Through reading and sorting out the literature, it can be seen that SLAM technology has greater advantages in biomedicine compared with traditional surgical procedures. SLAM technology greatly improves the efficiency of minimally invasive surgery and intraperitoneal surgery, improves the success rate of surgery and relieves the pressure on doctors. According to this study, different algorithms in SLAM technology can produce different degrees of accuracy. In the process of research, new research methods are constantly innovated to improve the accuracy of SALM internal imaging and the accuracy of feature matching. And the following conclusions are drawn through comparative experiments:

(1) The method based on K-Means and Superpoint algorithm is used to extract image feature points, which is more stable than the traditional algorithm and luminal image feature extraction results.

(2) The improved pose estimation algorithm of monocular laparoscopic image based on OrB-SLAM can improve the accuracy of ORB feature matching and thus improve the accuracy of laparoscopic image depth map.

(3) By calculating the NCC matching cost of multi-baseline observation frames, combined with SLAM pose estimation results, full pixel depth extraction of laparoscopic images was realized, and the accuracy and density of 3D reconstruction results were improved.

At the same time, the study also found that there are shortcomings in today's technology。Due to insufficient practicability, it takes a lot of time in the process of feature extraction and reconstruction of point cloud, and the time increases with the increase of scale.

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