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Research on 2D Representation Method of Wireless Micro-Ball Endoscopic Images

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***Abstract*—Nowadays the interpretation of the images acquired by wireless endoscopy system is a tedious job for doctors. A viable solution is to construct a map, which is the 2D representation of gastrointestinal (GI) tract to reduce the redundancy of images and improve the understandability of them. The work reported in this paper addresses the problem of the 2D representation of GI tract based on a new wireless Micro-Ball endoscopy system with multiple image sensors. This paper firstly models the problem of constructing the map, and then discusses mainly on the issues of perspective distortion correction, image preprocessing and image registration, which lie in the whole problem. The perspective distortion correction algorithm is realized based on attitude angles, while the image registration is based on phase correlation method (PCM) and scale invariant feature transform (SIFT) combined with particular image preprocessing methods. Based on R channels of images, the algorithm can deal with 26.3% to 100% of image registration when the ratio of overlap varies from 25% to 80%. The performance and effectiveness of the algorithms are verified by experiments.**

I. Introduction

The wireless endoscopy system is widely used in human digestive tract examination in recent years because of its superiority in the check of small intestine without pain in comparison with the traditional endoscopy. But it is a tedious task which requires considerable experience for doctors to interpret images acquired by the wireless capsule endoscopy system, because the amount of images is too large and the images are not suited for observation. The reason for the unintelligibility of images is that the wireless endoscopic images may be not the ones captured by the camera facing to the internal surface of GI tract and their contents are difficult to be recognized. If a map, which is the 2D representation of GI tract, as shown in Fig. 1, can be generated, it will be easier for observation and doctors will be extricated from the tedious work of interpreting images.

Our research team has proposed a wireless Micro-Ball endoscopy system [1], which can make full view image capture possible. Then the GI tract map can be constructed, if we can register the images and stitch them together. As the endoscopic Micro-Ball is propelled by peristaltic movements within the GI tract and by gravity, the relationship between the captured images is not explicit. Compared to the traditional image registration, the most important and necessary step is to judge whether the two images can be registered or not. For this issue, a determine method has been proposed [2]. Besides, another challenge lies in the image distortion, which comes from the arbitrariness of shooting direction of cameras and distortion of soft tissue of GI tract.

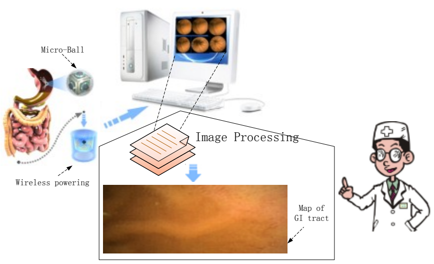

Fig. 1 2D representation of GI tract images for clinical diagnosis

This paper firstly models the problem of constructing the map and put forward possible difficulties lying in this process. And then it mainly discusses the issues of image distortion correction, image registration and some particular image preprocessing methods help for registration algorithms. The distortion correction method is based on attitude information which can be acquired by the attitude sensing system embedded in the Micro-Ball. And the phase correlation method (PCM) [8] and scale invariant feature transform (SIFT) [9] method, combined with particular preprocessing methods, are adopted in this paper for image registration. Eventually, the performance and effectiveness of the proposed methods are verified by experiments.

II. Algorithm Analysis And Design

A. Modeling of 2D Representation for GI Tract Images

To realize 2D representation for GI tract images, we firstly model the whole problem. As shown in Fig. 2, the process of constructing the map of GI tract can be divided into three main steps.

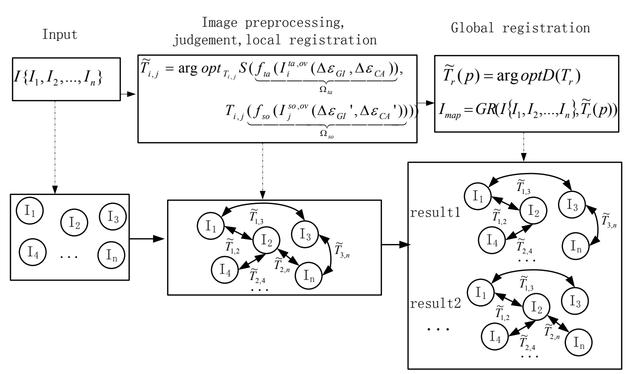

Fig. 2 Model of 2D representation for GI tract images

Step 1: Input image set: $I_{GI}\{I_1, I_2, ..., I_n\}$ for 2D representation.

Step 2: Solve the problem formulated in Equation (1), in order to complete local image registration.

$$\tilde{T}_{i,j} = \arg opt_{T_{i,j}} S(\underbrace{f_{ta}(I_i^{ta,ov}(\Delta\varepsilon_{GI}, \Delta\varepsilon_{CA}))}_{\Omega_{ta}}, T_{i,j}(\underbrace{f_{so}(I_j^{so,ov}(\Delta\varepsilon_{GI}', \Delta\varepsilon_{CA}'))}_{\Omega_{so}})) \quad (1)$$

where $I_i^{ta,ov}$ and $I_j^{so,ov}$ are the overlapping (ov) parts of the target (ta) image I_i^{ta} (i th image of I_{GI}) and of the source (so) image $I_j^{so,ov}$ (j th image of I_{GI}) respectively. In general image registration process, homologous information Ω_{ta} and Ω_{so} can be easier extracted from image pair with particular algorithms f_{ta} and f_{so}. However, for GI tract images, it is more difficult to select Ω and f, because GI tract images lack distinct features. Meanwhile, image distortion $\Delta\varepsilon_{GI}$ (caused by soft tissue distortion of GI tract) and $\Delta\varepsilon_{CA}$ (caused by random motion of Micro-Ball) also have negative effect on image registration. Generally, the homologous structures are superimposed by an optimization procedure $opt_{T_{i,j}}$, which maximizes the determination function S. The issue of image registration of GI tract images puts forward higher requirements on S. It needs to not only judge whether the two images can be registered or not, but also give the reliable parameters when they can be registered.

Step 3: Complete global registration of I_{GI}, to obtain the map (I_{map}) of GI tract. This process is mathematically formulated in Equation (2) and (3).

$$\tilde{T}_r(p) = \arg optD(T_r) \quad (2)$$

$$I_{map} = GR(I\{I_1, I_2, ..., I_n\}, \tilde{T}_r(p)) \quad (3)$$

where T_r is the set of transformation relationships between images having overlapped area, which is obtained by step 2. By a determination and optimization process $\arg optD$, the transformation sequence is sorted with specific priorities. Based on $\tilde{T}_r(p)$, the map of GI tract I_{map} can be constructed through a process of global registration (GR). In this process, the issue of error accumulation has to be solved to improve the result of 2D representation.

Based on discussions above, one may finds that there are so many challenges in 2D representation for GI tract images. This paper addresses mainly on the issues of image distortion $\Delta\varepsilon_{CA}$, image preprocessing with f and image registration $opt_{T_{i,j}} S()$.

B. Rectification Method for Micro-Ball images

Based on the discussions above, rectification of perspective distortion of wireless endoscopic images is essential to solve the issue of $\Delta\varepsilon_{CA}$. Some rectification methods have been proposed for particular applications [3-5].However, these methods mostly fulfill image correction based on corners detection. However, it is not easy to find reference points like corners in images of GI tract. Fortunately, the attitude of the Micro-Ball can be obtained by the attitude sensing system embedded in the Micro-Ball [7] and we can use this information to realize image rectification [6].

The distortion correction process is briefly shown in Fig. 3. The target of image correction is to obtain the relationship $V(\theta, \varphi, \alpha, focal)$ between the coordinates of p in the image pre-corrected (defined in the coordinate frame CF_c) and in the image post-corrected (defined in CF_c'). θ, φ and α (CF_c relative to CF_s) are, respectively, attitude angle roll, pitch and yaw, which are obtained by attitude sensing system. $focal$ is the focal length of the camera. CF_s is the coordinate system relative to the practical plane. Due to the coordinates of physical point $p(x, y, z)$ in the real world are constant, then $V(\theta, \varphi, \alpha, focal)$ can be derived.

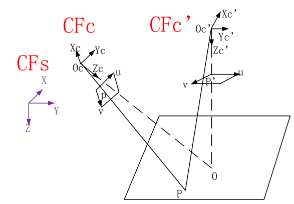

Fig. 3 The diagrammatic sketch of perspective distortion correction

In Micro-Ball system, the image correction problem is more complex because of three main issues: 1) image plane captured is changeable due to the motion of the Micro-Ball; 2) image distortion only occurs along with the longitudinal axis of the intestine; 3) multiple cameras bring multiple coordinated systems, the practical attitude information need to be derived from particular relationships among these coordinate systems.

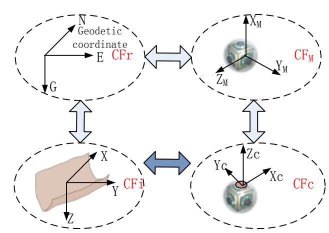

Fig.4 Coordinate systems in image correction for Micro-Ball images

As shown in Fig. 4, the coordinate systems are illustrated as follows.

CF_r: reference frame of attitude sensing system;

CF_M: carrier coordinate system of Micro-Ball;

CF_c: frame of the camera to be corrected (CF_c in Fig. 3);

CF_i: frame of the intestine;

CF_s: frame corresponding to the image plane captured (CF_s in Fig. 3).

In order to realize image correction, the relationship between CF_c and CF_s must be obtained, the derivation process includes four steps.

Step 1: $CF_M = \mathbf{R} \cdot CF_r$ (4)

where $\mathbf{R}$ is the rotation transform matrix obtained by attitude sensing system.

Step 2: $CF_c = \mathbf{T_1} \cdot CF_M$ (5)

This step is essential, because CF_M is fixed but CF_c is changing with the camera to be corrected. CF_c for different cameras can be human constructs based on the cubic structure of the cameras.

Step 3: $CF_r = \mathbf{T_2} \cdot CF_i$ (6)

This relationship is acquired based on the intestinal lumen detection combined with attitude sensing.

Step 4: $CF_i = \mathbf{T_3} \cdot CF_s$ (7)

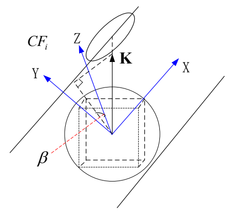

Fig. 5 The schematic diagram for image capture of Micro-Ball

As illustrated in Fig. 5, the vector $\mathbf{K}$ in CF_i corresponding to the shooting direction of the camera to be corrected is denoted as $\mathbf{k_{nt}}$ (Equation (8)).

$$\mathbf{k_{nt}} = \mathbf{T_2}^{-1}\mathbf{R}^{-1} \cdot \mathbf{k_{n0}} \ (n = 1,2,3,4,5 \ or \ 6) \quad (8)$$

where $\mathbf{k_{n0}}$ is $\mathbf{K}$'s vector representation in CF_M (Equation (9)).

$$\begin{aligned} &\mathbf{k_{10}} = (0,0,-1)^T, \mathbf{k_{20}} = (0,0,1)^T, \mathbf{k_{30}} = (1,0,0)^T \\ &\mathbf{k_{40}} = (0,-1,0)^T, \mathbf{k_{50}} = (-1,0,0)^T, \mathbf{k_{60}} = (0,1,0)^T \end{aligned} \quad (9)$$

With $\mathbf{k_{nt}}$, the angle β in Fig. 5 can be calculated and then $\mathbf{T_3}$ can be obtained (Equation (10)).

$$\mathbf{T_3} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & -\sin\beta \\ 0 & \sin\beta & \cos\beta \end{bmatrix}^T \quad (10)$$

According to Equation (4) ~ (10), the relationship between CF_c and CF_s can be obtained (Equation (11)).

$$CF_c = \mathbf{T_1} \cdot \mathbf{R} \cdot \mathbf{T_2} \cdot \mathbf{T_3} \cdot CF_s \quad (11)$$

Moreover, $\mathbf{T_1} \cdot \mathbf{R} \cdot \mathbf{T_2} \cdot \mathbf{T_3}$ can be used to obtain $V(\theta, \varphi, \alpha, focal)$ and realize image correction.

C. Image Registration and Preprocessing Methods

In order to realize robust image registration, the determine method proposed by our previous work [2] is adopted here to judge whether the two images can be registered or not first and then get the registration parameters.

Based on image analysis and experiments, it can be found that images of GI tract have few features for registration, so particular preprocessing methods are needed here. Based on the analysis of image histograms, it can be found that the intensity distribution of GI tract image focuses on specific range. Therefore, the image contrast is low and images lack high frequency components. A simple and notable solution to this problem may be image enhancement.

As illustrated in Fig. 6(a), original images are enhanced by the contrast stretch transformation shown in Fig. 6(b). It can be found that the histograms of images enhanced have more gray levels and the overlapping areas marked by the red circles are sharper. Therefore, it will help for image registration.

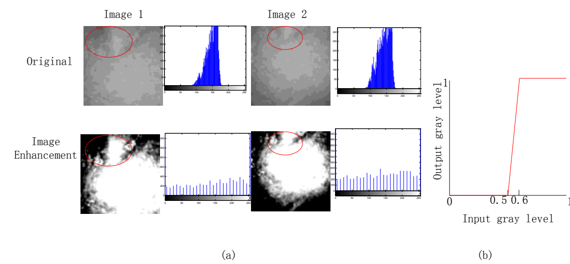

Fig. 6 (a) Image comparison before and after image enhancement; (b) The contrast stretch function adopted

III. EXPERIMENTS AND RESULTS

Experiments are designed aiming at verifying the proposed methods, mainly on testing the performance and effectiveness of specific methods of image correction (IC), image enhancement (IE) and image registration (IR).

A. Performance of Image Registration and Preprocessing Methods for GI Tract Images

Experiments on 1200 pairs of images cropped from real wireless capsule endoscopic images with different ratio of overlap and different relationships including translation, rotation and scaling, are made. And the original images are only images of internal wall of GI tract. The relationship between the success rate of registration (SROR) (Equation (12)) and the ratio of overlap (ROO) (Equation (13)) in particular situations is shown in Table 1. Experiments based on combination (Comb) of PCM and SIFT are also made.

$$SROR = \frac{\text{Number of image pairs successfully registered}}{\text{Number of image pairs tested}} \quad (12)$$

$$ROO = \frac{\text{Size of the overlapping area between image pair}}{\text{Size of the image tested}} \quad (13)$$

TABLE I. RELATIONSHIP BETWEEN SROR AND ROO FOR PARTICULAR SITUATIONS AND DIFFERENT ALGORITHMS(300 IMAGE PAIRS FOR EACH ROO)

Image setting	Methods setting		SROR (%)			
			80% ROO	50% ROO	40% ROO	25% ROO
Gray images	Original	PCM	1.3	0.3	0	0
		SIFT	1.3	0.3	0	0
		Comb	2.3	0.3	0	0
	IE	PCM	79	10.7	7.7	6
		SIFT	57	38.7	17.3	6.3
		Comb	82.3	40.7	20.7	11
R-channel	IE	PCM	99.7	38.7	20.7	23.3
		SIFT	62.3	38.7	14.7	6.7
		Comb	100	58.7	30	26.3
G-channel	IE	PCM	58.3	7	5.3	3
		SIFT	49	34.3	12	4
		Comb	68.3	36.3	15	6.3
B-channel	IE	PCM	66.7	30.3	21.7	13.3
		SIFT	38.3	27	16.3	3.7
		Comb	73	49	32.7	16.3

The experimental results shown in TABLE 1 illustrate four points: 1) image enhancement is essential and efficient in registration of GI tract images; 2) PCM shows superiority compared with SIFT in this specific situation of image registration, and its applicability is verified; 3) the images based on R channels show high contrast and the SROR is higher and this result comes from the characteristics of GI tract images. In future, we may adopt this method or do some research on other color spaces; 4) PCM combined with SIFT will have higher SROR than that of either. As illustrated in TABLE 1, PCM combined with SIFT can deal with 26.3% to 100% of image registration when the ROO varies from 25% to 80%, when there are translation, rotation and scaling existing between the input images which are based on R channels.

B. Necessity Validation of Rectification Method for Image Registration

Experiments on the same image group for verifying the necessity of image perspective distortion correction are also made. Due to the ROO is difficult to be controlled and the accurate attitude angles are not easy to be obtained in practical situation, we make simulation experiments. The original images are manually deformed respectively by α , θ and φ defined in section Ⅱ.B. And for each situation, the relationship between the decrement of success rate of registration (D-SROR) for distorted images compared with the result obtained with image rectification (set as 100%), can be obtained based on PCM. The final relationship between D-SROR with different distortion angles (DA) and ROO is obtained by the mean case of specific situations, and it is illustrated in Table 2.

TABLE II. RELATIONSHIP BETWEEN D-SROR AND ROO WITH DIFFERENT DISTORTION ANGLES(100 IMAGE PAIRS FOR EACH ROO)

ROO(%) / DA(°) \ D-SROR(%)	80	40	25
25	33.2	55.0	40.9
45	26.9	31.3	52.4

The experimental results shown in TABLE 2 illustrate that the decrement of SROR of distorted images compared to the results obtained with correction ranges between 33.2% and 55.0% even if DA is only 25°, when the ROO varies from 25% to 80%. Based on the results, it can be verified that image perspective distortion correction is essential before registration for wireless Micro-Ball images.

C. Actual Effect on Experimental Platform

The experimental platform for verifying the proposed algorithms includes Micro-Ball system, slide, a cylinder and experimental image, as shown in Fig. 7. Based on the attitude sensing system embedded in the Micro-Ball, the random error of pitch and roll is less than 3°, and the error of yaw is less than 6°.

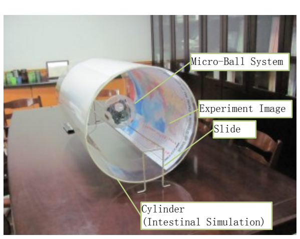

Fig. 7 Experimental platform

The Micro-Ball captures images when it travels along the slide, and image processing is implemented when the images uploaded onto the computer. As shown in Fig. 8, they are the results of image registration for one image pair (Fig. 8(a)) and a sequence of images (Fig. 8(b)). They are respectively registered with image perspective distortion correction and without it. It is illustrated that the algorithm proposed is feasible and effective. Image registration for Micro-Ball images may fail without perspective distortion correction (Fig. 8 (a)).

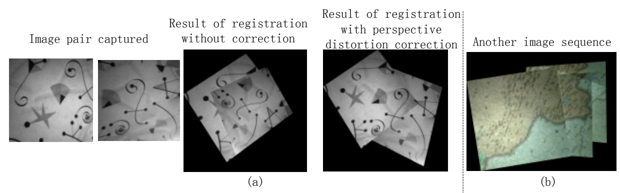

Fig. 8 Result of registration for pratical images

IV. CONCLUSION

This paper mainly discusses about the 2D representation method of GI tract based on wireless Micro-Ball, with an emphasis on some key technologies, including image perspective distortion correction, image preprocessing and image registration. The method of perspective distortion correction based on attitude angles for Micro-Ball images is analyzed and derived, while the image registration method is discussed with particular image preprocessing. Experimental results indicate that PCM combined with SIFT and image enhancement, based on R-channel of images shows superiority on SROR for GI tract images. And perspective distortion correction is essential before image registration. PCM combined with SIFT can deal with 26.3% to 100% of image registration when the ROO varies from 25% to 80%, when there are translation, rotation and scaling existing between the input images which are based on R channels.

In future, we will do some research on local image registration method for soft tissue of GI tract and global registration methods.

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