Incorporation of 3D Model and Panoramic View for Gastroscopic Lesion Surveillance

Yun Zong[1,2], Weiling Hu[3], Jiquan Liu[1,2(✉)], Xu Zhang[1,2], Bin Wang[1,2], Huilong Duan[1,2], and Jianmin Si[3]

[1] College of Biomedical Engineering and Instrument Science, Zhejiang University, Hangzhou 310027, China
{21315039,liujq,zhangxu_bme,11015021,duanhl}@zju.edu.cn
[2] Key Laboratory for Biomedical Engineering, Ministry of Education, Zhejiang University, Hangzhou 310027, China
[3] Institute of Gastroenterology, Sir Run Run Shaw Hospital, Zhejiang University, Hangzhou 310016, China
ringwh@hotmail.com, sijm@zju.edu.cn

Abstract. Natural Orifice Transluminal Endoscopic Surgery (NOTES) is widely used for clinical diagnoses. However, NOTES has two main problems: difficulties brought by endoscope's flexibility and narrow view of endoscope. Image-guided system is helpful to deal with these problems. In our previous work, a computer aided endoscopic navigation system (CAEN) was developed for gastroscopic lesion surveillance. In this paper, 3D model and panoramic view are incorporated into CAEN with three improvements: selection of reference and tracking features; perspective projection for constructing local and global panoramic view; 3D surface modeling using structure from motion. The system is evaluated from three clinic applications: broadening the view, non-invasive retargeting, and overall lesion locations. The evaluation results show that the mean accuracy of broadening the view is 0.43 mm, the mean accuracy of non-invasive retargeting is 7.5 mm, and the mean accuracy for overall lesion diagnosis is 3.71 ± 0.35 mm.

Keywords: 3D surface modeling · Feature selection · Image-Guided system · NOTES · Panoramic view

1 Introduction

In minimally invasive surgery, a new form named Natural Orifice Transluminal Endoscopic Surgery (NOTES) was proposed by the Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR) in 2005. As NOTES reduces patients' pain and promotes postoperative recovery, it's regarded as a new evolution of minimally invasive surgery [1]. However, many problems of NOTES are proposed: first, as NOTES is carried out by surgeons, endoscope's flexibility troubles surgeons. Without assistance to achieve triangulation or to obtain consistent images, performing a complex surgery is difficult [2]; second, endoscope provides narrow view for surgeons, space orientation of surgical sites and image orientations both make troubles for surgeries [3].

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To solve these problems, Image-guided system is employed, which is an assistant part of surgery. Tracking device of Image-guided system combined with image processing methods guide the experts to locate and target lesions in surgery. Bimanual manipulation was applied to assist NOTES, a standard dual channel endoscope (DCE) was compared with the combination of the R-Scope and the direct drive endoscope system (DDES) in [4]. In paper [5], Da Vinci Surgical System, which was firstly employed for gastric cancer in 2002 [6], was combined with 2D and 3D vision to confirm the orientations of images. Real-time tracking of the endoscope camera was proved helpful to locate surgical sites with a reference coordinate system [7], image-registration techniques improved excellent performance of surgery task in laparoscopy [8, 9]. 3D reconstruction and image stitching methods were beneficial for these tasks. To recover 3D depth information under endoscopy, new methods were developed, including the Gaussian mixture model [10], the non-rigid SFM theory [11]. In a word, Image-guided system was proved useful in NOTES.

In our previous work, a computer aided endoscopic navigation system (CAEN) was developed for non-invasive biopsy [12]. The system consists of a 6-DOF tracking endoscope device and a computer simulated work station. In the process, the tip of the tracking endoscope was used to touch the lesion; then the work station recorded the lesion's location; in the follow-ups, the lesion's location would guide the endoscopist in retargeting the lesions. We devoted to 3D reconstruction, it was proposed in paper [13], feature tracking was a start; then SFM was applied to reconstruct local patches; finally, all those patches were merged, which showed a prominent performance in endoscopy navigation. Panorama is another promising methodology to solve the narrow field of view (FOV) problem. In this paper, we improve the CAEN system by merging 3D model and panoramic view into the system. The improved system consists of three parts: feature selection, perspective projection, and 3D surface modeling. It has three clinic applications: broadening the view, non-invasive retargeting, and overall lesion diagnosis. The system is described as follows: methods are described in Sect. 2, results of this system are described in Sect. 3, and conclusion is described in Sect. 4, acknowledgement is in the last section.

2 Methods

2.1 Overview

The improved system consists of: a work station, an endoscope, and a 6-DOF position tracking device, as mentioned in CAEN. The 6-DOF position tracking device is made up of an electronic unit device, a sensor probe, and a magnetic transmitter. The system is devoted to assisting the endoscopist in operating on the stomach accurately. Figure 1 depicts the workflow of the system. Feature selection is the first step, and then perspective projection and 3D surface modeling are employed.

2.2 Feature Selection

Reference features and tracking features are selected during the gastroscopy. The standard of selecting reference points is that they can be easily found and touched by

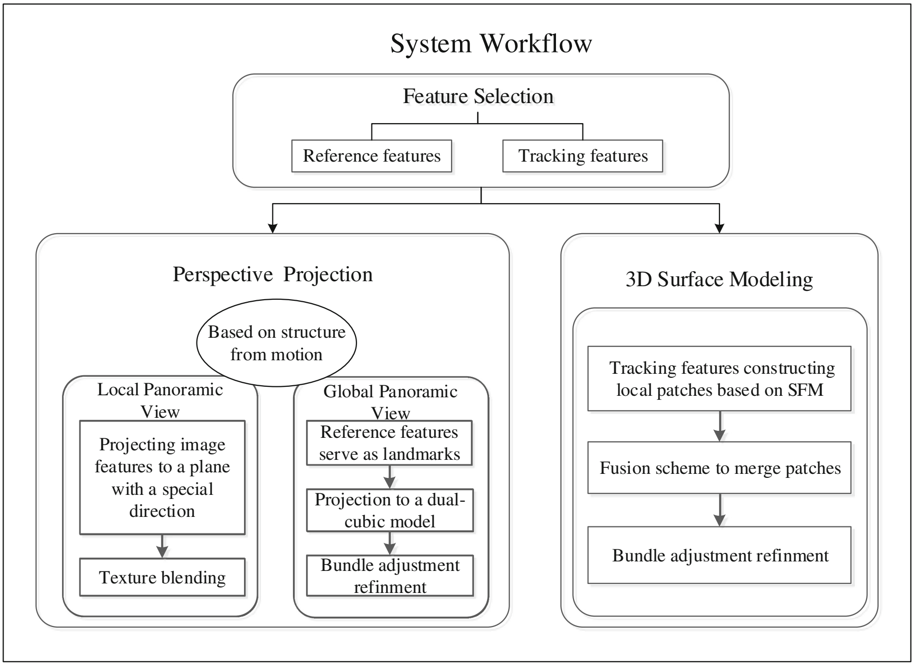

Fig. 1. System workflow: including feature selection, perspective projection, and 3D surface modeling

the endoscopist. According to anatomic characteristics of the stomach, the cardia, pylorus, junction of the anterior body wall and angularis, junction of the posterior body wall and angularis, middle of the antrum are selected as reference points. Reference points have to be touched at the beginning, and locations of them should be recorded for follow-up examinations. Tracking features are selected by endoscopist from images during the gastroscopy procedure. Image registration method is applied during tracking feature selection procedure. Reference features and tracking features are both employed to the following perspective projection and 3D surface modeling procedures.

2.3 Perspective Projection

The system implements perspective projection to construct the panoramic view. Panoramic view is one of the main methods in solving narrow FOV, including local panoramic view and global panoramic view.

During intra-operation, local panoramic view uses perspective projection. First, the position information of camera and images are transformed by tracking device; then images are projected onto a plane to construct a wider view based on SFM. Relationship between an image point $p_i = \left(x_i, y_i\right)^T$ and its corresponding 3D point $P_i = \left(X_i, Y_{i,}, Z_i\right)^T$ is described in the following equation:

$$M^{2*3}P_i = p_i \tag{1}$$

Projection matrix M^{2*3} is multiplied by internal matrix and external matrix. Internal matrix denotes internal information of camera, external matrix denotes the rotation and translation. Tracking feature points are selected and recorded by the 6-DOF tracking device. These image points are projected onto a plane based on Eq. (1). To achieve minimal errors, the plane is parallel with the camera's scope. We only select images adjacent to the current displayed image, and these images are captured using an endoscope with a very small skew angle. Finally, the composited image should be mapped with the texture information from the native gastroscopic images. We employ the multi-resolution pyramidal algorithm to blend the composited images [14]. With local panoramic view, the endoscopist is able to get a broadened view.

In post-operation, the endoscopist reviews images in order to reduce misdiagnoses. In this paper, we use global panoramic view to assist the endoscopist in reviewing. The global panoramic view uses a dual-cubic projection model which is similar to hemi-cubic model employed in [15]. As soon as the tracking endoscope enters the stomach, three of the reference points (including the cardiac orifice, angular incisures and pylorus) are marked as landmarks, then the position information captured by device starts to match with the dual-cubic model, and the corresponding images are projected onto the faces of dual-cubic model based on Eq. (1). Finally, the bundle adjustment algorithm is adopted to refine the model. As global panoramic view devotes to unfolding the surface of stomach, endoscopists are able to find overall lesions with reference points, so that misdiagnoses can be reduced.

2.4 3D Surface Modeling

In gastroscopy, to assist the endoscopist in accurate retargeting of lesions, 3D model is used for gastric navigation. Similar to the reference points, the biopsy sites are touched as tracking features, then the global coordinates are recorded by the work station. Using Eq. (1), SFM theory is adopted to reconstruct the local 3D gastric internal patches; subsequently, a novel fusion scheme is introduced to merge the local 3D patches; finally, BA algorithm is employed to refine the reconstructed model. This method renders a real-time gastric 3D scene as well as updates the local scene according to current displayed image frames, which indicates that the 3D scene can represent actual gastric deformation. With this model, some detailed information are displayed, surgical navigation is more accurate.

The procedure of non-invasive retargeting involves first examination and follow-up examinations. In all examinations, all five reference points has to be touched with the tip of the 6-DOF endoscope device and recorded, they are used for global coordinate registration. In the follow-up examinations, the global coordinate's registration is estimated. Afterwards, the recorded biopsy sites' positions are transformed and then marked in real endoscopic videos in order to guide the endoscopist in retargeting the biopsy sites.

3 Results

For this study, 35 patients with histories of gastric diseases were enrolled, and 15 patients of them had follow-up examinations. All patients provided a written informed consent for all examinations. The gastroscopy examination was performed by a skilled endoscopist (Table 1).

Table 1. Clinical characteristics

Variables	Number
Median age, year (range)	57.6 (38–77)
Sex (female/male)	21/14 Smoking
Smoking	13
Alcohol	15

As the system works in both intra-operation and post-operation. During the intra-operation, the system has two applications, broadening the view and navigation; in the post-operation procedure, the system contributes to overall lesion diagnosis. The results of these applications are evaluations of the system.

3.1 Broadening the View

In gastroscopy, the local panoramic view was rendered in real time. A 1500 * 500 pixels size canvas was created for the purpose of depicting complete neighbor environment of the lesions; according to the gastroscopic camera's motion and the distance between camera and the projection plane, neighbor images were selected. The local panoramic view used four sites, which include antral, stomach body, pylorus and angularis. They were projected onto the center of the canvas. Texture blending algorithm showed a good performance. The mosaicking error for local panoramic was 0.43 mm.

3.2 Non-invasive Retargeting

In order to compare the results between the non-invasive retargeting and tattooing, the selected biopsy sites were marked by tattooing and the 6-DOF endoscopy device respectively. In the first examination, a 3D model was built. Three months after the first examination, a follow-up endoscopy was performed with the system, and the global coordinates' registration was estimated between the two examinations. The distance between the targeted points and the tattooing area's center was designated as the accuracy of non-invasive retargeting. Moreover, the system's touching time and tattooing time were recorded. The mean accuracy was 7.5 mm, and the operation time was much shorter than the tattooing time (see Table 2).

Table 2. Accuracy of the retargeting.

Biopsy location	Accuracies: (mean_SD) mm	Marking time: (mean_SD) s (Tattooing/CAEN)
Angularis	5.2 ± 2.8	12 ± 4.1/3 ± 1.8
Antral lesser curvature	7.2 ± 2.0	12 ± 4.4/2 ± 0.8
Antral greater curvature	6.3 ± 3.1	11 ± 3.6/2 ± 0.7
Antral posterior wall	8.2 ± 1.6	12 ± 5.5/2 ± 0.7
Antral anterior wall	7.9 ± 1.3	13 ± 5.2/2 ± 0.7

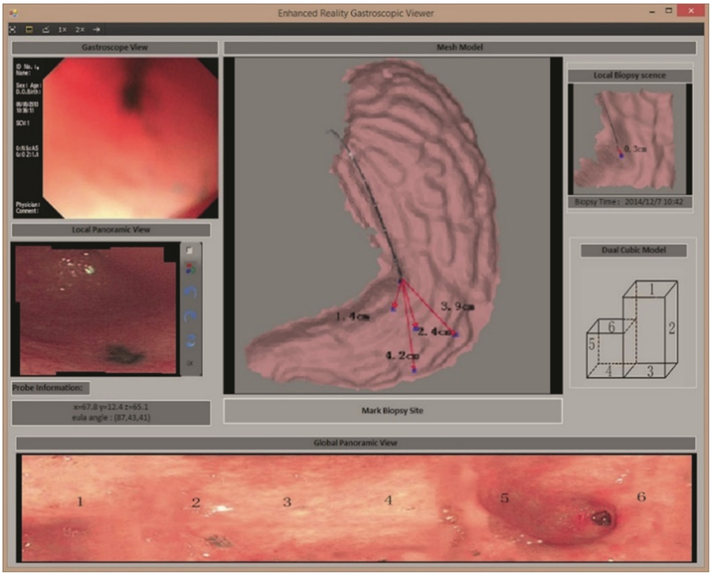

Fig. 2. UI of the system

3.3 Overall Lesion Diagnosis

To validate the performance of the global panoramic view, 1000 points were randomly selected from panoramic view and re-projected onto the original frames. Euclidean distances for the corresponding points were regarded as the accuracy and the direct measured distance's unit was the pixel. To measure clinical physical measure result, biopsy forceps with a span diameter of 6 mm was used to touch the stomach, and the captured images provided a standard for converting the accuracy from pixel to millimeter. The mean error for global panoramic view was 3.71 ± 0.35 mm.

In Fig. 2, the top-left displays the current gastroscopy view seen by the endoscopist; local panoramic view shows the broadening view of images around the camera; probe information is also transmitted on UI; 3D model reconstructed by SFM is displayed in Mesh Model, marked biopsy sites are shown on both mesh model and local biopsy scene; global panoramic view is also shown on the bottom of UI.

Compared with the other computer-aided systems, our system has the following advantages: first, most systems only focus on intra-operation, such as the pathological site retargeting which uses affine deformation modelling [16], while the lesion diagnosis of our system works in both intra-operation and post-operation; second, as the operation of gastroscopy is flexible, many systems with geometry constraints are not accurate enough. For example, because the epipolar lines have many constraints on the camera parameters, the biopsy site re-localization method proposed in [17], which is based on the computation of epipolar lines, isn't accurate enough during the gastroscopy, while our system is able to deal with this problem by the gastroscopy tracking device; third, our system is easy to operate, as it has less operation steps than lots of computer-aided systems.

4 Conclusion

Currently, endoscope's flexibility and narrow view are two main problems of NOTES. In this paper, based on our previous system CAEN, 3D Modeling and Panoramic View are merged into CAEN. The developed system's workflow has three parts, including feature selection, perspective projection, and 3D modeling. The system makes several contributions: broadening the view, non-invasive retargeting, and overall lesion diagnosis. The results show that this system is likely suitable for clinical applications. However, the limitations of the current system should be emphasized: first, many operations are semi-automatic and associated with the endoscopist's skills; second, computational cost and accuracy need to be improved. In the future, more automatic methods will be involved; accuracy and consuming time will be improved; Moreover, more volunteers and endoscopists should be enrolled.

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References

1. Coughlin, G., Samavedi, S., Palmer, K.J., Patel, V.R.: Role of image-guidance systems during NOTES. J. Endourol. **23**, 803–812 (2009)
2. Bardaro, S.J., Swanstrom, L.: Development of advanced endoscopes for natural orifice transluminal endoscopic surgery (NOTES). Minim. Invasive Ther. Allied Technol. **2006**(15), 378–383 (2006)
3. Swanstrom, L., Swain, P., Denk, P.: Development and validation of a new generation of flexible endoscope for NOTES. Surg. Innov. **16**, 104–110 (2009)

4. Spaun, G.O., Zheng, B., Martinec, D.V., Cassera, M.A., Dunst, C.M., Swanstrom, L.L.: Bimanual coordination in natural orifice transluminal endoscopic surgery: comparing the conventional dual-channel endoscope, the R-Scope, and a novel direct-drive system. Gastrointest. Endosc. **69**, 39–45 (2009)
5. Blavier, A., Gaudissart, Q., Cadiere, G.B., Nyssen, A.S.: Impact of 2D and 3D vision on performance of novice subjects using da Vinci robotic system. Acta Chir. Belg. **106**, 662–664 (2006)
6. Hashizume, M., Shimada, M., Tomikawa, M.: Early experiences of endoscopic procedures in general surgery assisted by a computer -enhanced surgical system. Surg. Endosc. **16**(8), 1187–1191 (2002)
7. Cleary, K., Peters, T.M.: Image-guided interventions: technology review and clinical applications. Annu. Rev. Biomed. Eng. **12**, 119–142 (2010)
8. Vosburgh, K.G., San, J.E.R.: Natural orifice transluminal endoscopic surgery (NOTES): an opportunity for augmented reality guidance. Stud. Health Technol. Inform. **125**, 485–490 (2007)
9. Vosburgh, K., Stylopoulos, N., Thompson, C., Ellis, R., Samset, E., San, J.E.R.: Novel real time tracking interface improves the use of laparoscopic and endoscopic ultrasound in the abdomen. Int. J. Comput. Assist. Radiol. Surg. **1**, 282–284 (2006)
10. Giannarou, S., Yang, G.-Z.: Tissue deformation recovery with gaussian mixture model based structure from motion. In: Linte, C.A., Moore, J.T., Chen, E.C.S., Holmes III, D.R. (eds.) AE-CAI 2011. LNCS, vol. 7264, pp. 47–57. Springer, Heidelberg (2012)
11. Zhu, S., Zhang, L., Smith, B.M.: Model evolution: an incremental approach to non-rigid structure from motion. In: 2010 IEEE Conference on Computer Vision and Pattern Recognition (2010)
12. Liu, J.Q., Wang, B., Hu, W.L., Zong, Y., Si, J.M., Duan, H.L.: A non-invasive navigation system for retargeting gastroscopic lesions. Biomed. Mater. Eng. **24**(6/2014), 2673–2679 (2014)
13. Wang, B., Liu, J.Q., Zong, Y., Duan, H.L.: Dynamic 3D reconstruction of gastric internal surface under gastroscopy. J. Med. Imaging Health Inform. **4**, 797–802 (2014)
14. Burt, P.J., Adelson, E.H.: A multiresolution spline with application to image mosaics. ACM Trans. Graph. (TOG) **2**(4), 217–236 (1983)
15. Behrens, A., Stehle, T., Gross, S., Aach, T.: Local and global panoramic imaging for fluorescence bladder endoscopy. In: Annual International Conference of the IEEE on Engineering in Medicine and Biology Society, EMBC 2009, pp. 6990–6993 (2009)
16. Ye, M.L., Giannarou, G., Patel, N., Teare, J., Yang, G.Z.: Pathological site retargeting under tissue deformation using geometrical association and tracking. In: The 16th International Conference on Medical Image Computing and Computer Assisted Intervention (2013)
17. Allain, B., Hu, M.X., Lovat, L.B., Cook, R., Ourselin, S., Hawkes, D.: Biopsy site re-localisation based on the computation of epipolar lines from two previous endoscopic images. In: The 12th International Conference on Medical Image Computing and Computer Assisted Intervention (2009)