Method of Retrieving Multi-Scale Objects from Optical Colonoscopy Images based on Image-Recognition Techniques

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***Abstract*—This paper proposes a method of retrieving multi-scale objects from optical colonoscopy images based on image-recognition techniques. Optical colonoscopy is the most common approach to diagnosing bowel diseases through direct colon and rectum inspections. Periodic optical-colonoscopy examinations are particularly important for detecting cancers at early stages while still treatable. However, diagnostic accuracy is highly dependent on both the experience and knowledge of the medical doctor. Moreover, it is extremely difficult, even for specialist doctors, to detect the early stages of cancer when obscured by inflammations of the colonic mucosa due to intractable inflammatory bowel diseases. In order to assist diagnoses with optical colonoscopy, this paper proposes a retrieval method for colonoscopy images that can cope with multi-scale objects. The proposed method can retrieve similar images despite varying sizes of the target objects. Through experiments conducted with real clinical colonoscopy images, we demonstrate that the method is able to retrieve objects of any size at high levels of accuracy.**

Keywords*—colonoscopy; image retrieval; multi-scale; image recognition; ulcerative colitis

I. INTRODUCTION

Recently, the number of cancer patients around the world has been increasing. Within recent decades, the number of newly-diagnosed patients has increased by 100,000, reaching approximately 850,000 cases within Japan in 2011 [1]. The gastroenterological cancers, which include stomach, colon and rectum areas, have particularly high incidence rates, and are projected to become the most common cause of death by 2014 [2]. On the other hand, data also indicates that there have been significant improvements in survival rates at 5-years post-diagnosis, because recent medical advances are increasingly helping to detect cancer at treatable early stages of development. For cancers of the colon and rectum areas, optical colonoscopy is the most popular approach towards screening, surveillance and treatment. Using colonoscopy, medical doctors can directly observe the colonic mucosa and obtain detailed information about the condition of the colon. This means that optical colonoscopy is especially suited for the early detection of cancer.

However, diagnostic accuracy is highly dependent on both the experience and knowledge of medical doctors, because they must make immediate identifications by closely observing the microscopy images while simultaneously carrying out the colonoscopy examination. It is, therefore, extremely difficult, even for specialist doctors, to detect the early stages of a cancer within inflammations of the colonic mucosa due to intractable inflammatory bowel diseases (IBDs), such as ulcerative colitis (UC) and Crohn's disease (CD). Moreover, prolonged colonic inflammations increase the risks of colorectal cancer, with incidences at approximately 3.7% on average [3]. Thus, in order to reduce mortalities due to colorectal cancer associated with IBDs, standard recommendations for early detection in the United States and Europe are to conduct surveillance colonoscopy with random biopsies, where multiple tissue samples are mechanically taken at equal intervals across the broad areas of flat and apparently abnormal colonic mucosa [4]. In contrast, standard recommendations for early detection within Japan are to conduct targeted biopsies, where tissue samples are only taken from locations suspected of being cancerous [4]. Although targeted biopsies are considered less onerous for patients compared to random biopsies, it is vital to develop assistance technology that can positively contributing to improving detection accuracies for targeted biopsies.

Aimed at enhancing UC diagnoses using optical colonoscopy, we have already proposed a method of objective evaluations [5], which tenders classification results according to UC severity, and a method of retrieving content-based images [6], which returns reference images based on degree of similarity to the images being diagnosed. Those prior proposals were developed based on image-recognition techniques, such as image preprocessing and geometrical feature extraction. However, these prior methods are unable to adequately deal with variations in the sizes of retrieval objects within optical colonoscopy images. If colonoscopy images are captured with a discrete focal distance, the visible size of a target object within the colonoscopy images will influence the process of feature extraction, which, in turn, will affect classification computations and retrieval results. That means it is even possible to obtain different results for the same target object, due to differences in size of the object within different images. Thus, to realize effective assistance technology for practical applications, it is essential to have a new retrieval method that is not totally dependent on visible dimensions.

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Compensating for effects due their visible sizes within optical colonoscopy images, this study seeks to realize a method of retrieving multi-scale objects from optical colonoscopy images based on higher order local auto-correlation (HLAC) [7]. In order to retrieve similar objects that differ in their visible sizes, the proposed method generates integral HLAC feature tables that are calculated by a newly-extended HLAC extraction method based on an integral image technique [8]. As the HLAC features for an arbitrarily-sized clipping area can be reconfigured from a table of integral HLAC features, this approach is far more efficient than the conventional HLAC method.

This paper is organized as follows: In Section 2, we explain the methodology of the proposed method. Section 3 presents the results of the experiment conducted to verify the proposed method. Finally, a summary of this study is provided in Section 4.

II. Methodology

A. Overview of the Proposed Retrieval Method

The proposed method is essentially an extension of our previous content-based image retrieval (CBIR) method [6], which effectively combines three key elements of preprocessing, geometric feature extraction and similarity evaluations. More specifically, this study improves the geometric feature extraction component in order to handle the retrieval of multi-scale objects by utilizing the integral image technique [8]. Fig. 1 illustrates retrieval processing using the integral feature table. By applying the integral technique to a database of extracted features for retrieval targets, it is possible to efficiently compute the geometrical features of an arbitrarily-sized region so that objects of various visible sizes can be retrieved during the retrieval phase. A region, that is arbitrarily determined both in terms of size and location, is clipped from the integral feature table and a similarity evaluation between its computed feature v_i and the extracted query feature v_{query} is calculated. Retrieval processing is repetitively executed for all retrieval candidates within the database and the results for all similarity evaluations are compared in producing the retrieval results. The main procedures of the proposed method are described in more detail in the following subsections.

B. Image Preprocessing

In comparing optical colonoscopy images for the same object taken with different focal distances, both object size and object color are considered as points of contrast, because the illumination conditions for each image are a function of the focal distance. In our previous work [5], we reported that the saturation element of the HSV color space results in steady histograms for images of uneven brightness. Moreover, the saturation element can express the appearance of the colonic mucosa. Accordingly, for preprocessing, we adopt the saturation element converted from the original colonoscopy images for the RGB color space. In addition, bright blobs within colonic images are interpolated by a method of image inpainting [9] prior to conversion, because the saturation element cannot be converted from bright blobs.

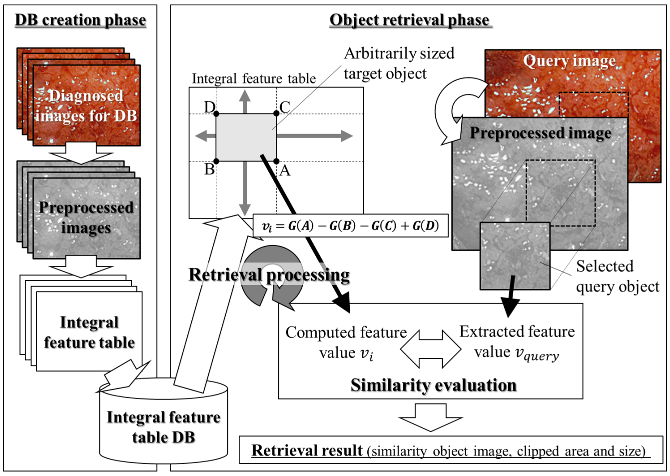

Fig. 1. Illustration of retrieval processing using the integral feature table.

C. Feature Extraction and the Integral Feature Table

As a basic framework for feature extraction, the proposed method adopts the higher order local auto-correlation (HLAC) method [7] that can calculate some geometrical features. The HLAC features, F, represent the expressed characteristics for a complete image, derived from the product-sum operations of the following formula that represents autocorrelations:

$$F_N = \sum_r I(r) \cdot I(r + a_1) \cdots I(r + a_n) \tag{1}$$

where N is the order of autocorrelation, r is the X-Y coordinate vector of the colonoscopy image, $I(r)$ is the pixel value at r, and a_i $(i=1 \ldots M)$ are displacement vectors around r. 25 masks are formed by the configurations of r and a_i, restricted by the second orders of autocorrelation $(N=0,1,2)$ within a 3x3 area around r.

As it is necessary to reiterate the process of image clipping at arbitrarily determined sizes and locations and feature extraction in order to realize multi-scale object retrieval, our previous HLAC algorithm is not particularly suitably, because the features are irreversible values and new calculations must be executed when the target area is changed. Accordingly, within this study, the HLAC method is extended with the incorporation of an integral feature table that can easily generate the feature of the arbitrary area at low calculation costs based on integral image techniques [8]. The value G at any X-Y coordinate $r(x,y)$ in the integral feature table is the sum of all the autocorrelations f at r, according to the following formula:

$$G(r(x,y)) = \sum_{x' \le x} \sum_{y' \le y} f(r(x', y')) \tag{2}$$

In database-creation phase, the integral image features are generated for every HLAC feature according to the following formula:

$$\begin{aligned} &G_N(r(x,y)) \\ &= \sum_{x' \le x} \sum_{y' \le y} I(r(x', y')) \cdot I(r(x', y')) \cdots I(r(x', y') + a_N) \end{aligned} \tag{3}$$

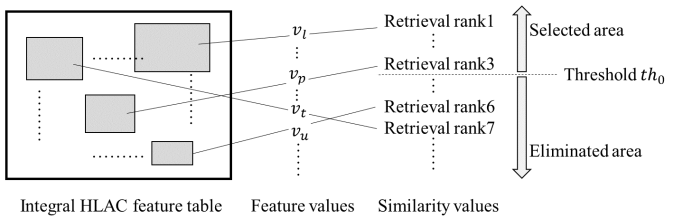

Fig. 2. Area selection for an image using the integral HLAC feature table.

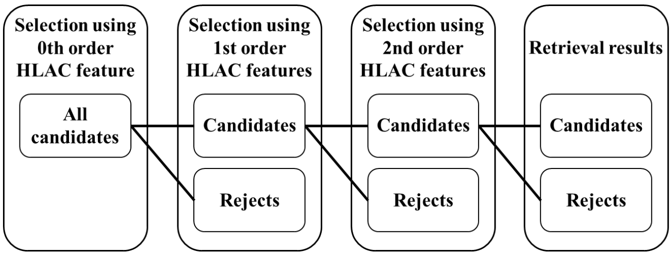

Fig. 3. Stepwise image selection.

D. *Retrieval Processing and Similarity Evaluations*

To evaluate the similarity between a query object and any object within the database, a similarity value is calculated from the Euclidean distances of both features. In this study, retrieval processing consists of the two steps of area selection and image selection. In the area selection step, an area with a high degree of similarity is selected according to the retrieval threshold th_0 using integral feature table at 0th order HLAC, as shown in Fig. 2. In the image selection step, we adopt stepwise selection for all autocorrelation orders, as shown in Fig. 3. The retrieval thresholds for each selection are defined separately. This stepwise algorithm can efficiently retrieve a similar object from many retrieval targets by whittling down the candidates.

III. Experiments

This study reports on two verification experiments conducted to examine both the potential to retrieve multi-scale objects and retrieval performance for actual colonoscopy images. The details of the experimental data and the experiments are described in the following subsections.

A. *Experimental Data Conditions*

In the first experiment, we used eleven colonoscopy images. The nine images for the three UC types were quasi-images that had been expanded and subsequently shrunk for a clipped object from the three colonoscopy images respectively, as shown in Fig. 4(a). The two images for the actual colonoscopy images show the same mucosal inflammation at different sizes, as shown in Fig. 5(a). In the second experiment, 100 colonoscopy images, which were obtained from 13 UC patients, were used as retrieval targets and three of the images were used as query images. These images include various degrees of UC inflammation severity (from mild, moderate, to severe), as shown in Fig. 6. These images were created by trimming the original colonoscopy images to 800x600 pixels in size. For retrieving multi-scale objects, target objects were computed within a range of plus/minus 10% of the query size from the integral feature table.

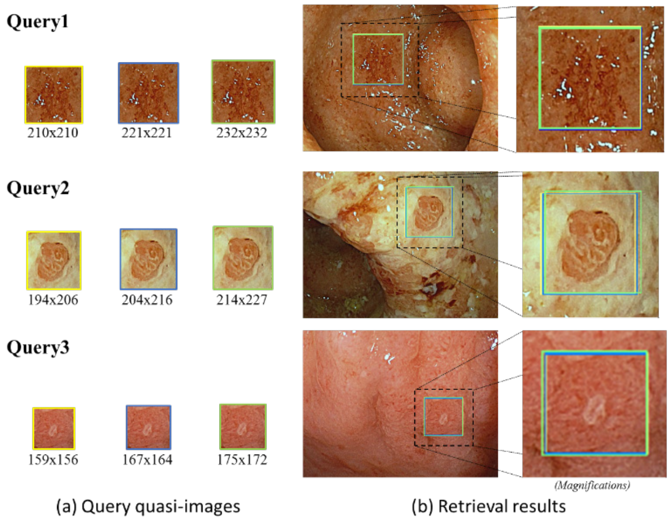

Fig. 4. Experimental data and retrieval results for quasi-images.

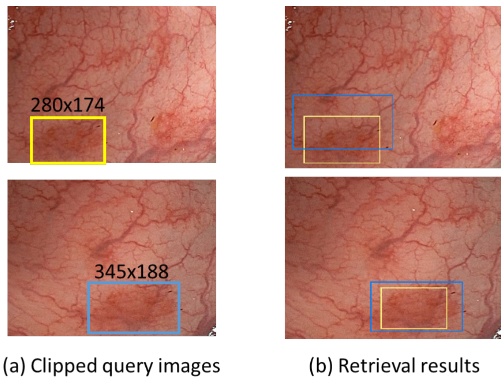

Fig. 5. Experimental results for two actual images of the same object.

B. *Experimental Results for Capability to Retrieve Multi-Scale Object*

Table 1 shows the retrieval results, which are clipped area, size and similarity value, of quasi-images of three sizes. These sizes are approximately-same for each quasi-image. Moreover, Fig. 4(b) presents the retrieval results for the quasi-images of three sizes. Comparisons of the results for these quasi-images indicate that the proposed method is capable of retrieving objects of any size at high accuracy. Fig. 5(b) presents the cross-validation results for the two images. In this cross-validation, when one image was assigned as the query object with clipping, the another image was treated as the retrieval target. The result for the actual images also clearly demonstrate the feasibility of the proposed method for retrieving multi-scale objects.

C. *Experimental Result for Retrieval Performance using Actual Images*

Fig. 7 shows the top three retrieval rankings for the three query images. These images represent heterogeneous symptoms. For each image, the proposed method was able to retrieve similarity categorized images from among the 100 images. In particular, the results demonstrate that the proposed method functions successfully even for severely inflamed mucosa, because the proposed integral feature can adjust for the size of the colonic mucosa within inflammations.

TABLE 1. Experimental results for quasi-images.

Query quasi-images	Top-left coordinate		Clipping size		Similarity value
	X	Y	Width	Height	
Query 1-1	204	118	208	208	1375.70
Query 1-2	205	121	208	208	3045.13
Query 1-3	203	118	209	209	2896.66
Query 2-1	416	66	192	204	2868.30
Query 2-2	420	67	192	203	2402.87
Query 2-3	425	61	195	206	2879.90
Query 3-1	500	275	157	154	0.00
Query 3-2	500	275	156	154	853.96
Query 3-3	495	272	161	159	1368.20

Fig. 6. 100 retrieval target images, which are actual colonoscopy images, used in the second experiment.

IV. Conclusion

This study has proposed a method of retrieving multi-scale objects from optical colonoscopy images based on HLAC. In order to retrieve similar objects that are similar to a target object even though based on different visible sizes, the proposed method generates tables of integral HLAC features, which are calculated by a newly-extended HLAC extraction method based on an integral image technique. As the HLAC features for an arbitrarily-sized clipping area can be reconfigured from the table of integral HLAC features, this approach is far more efficient than the conventional HLAC method. In the conducted verification experiments using actual colonoscopy images obtained from patients, we demonstrated that our method is capable of retrieving objects of any size at high accuracy and that the method is fully effective for real colonoscopy images. We hope that the proposed method can become a key technology in developing computational assistance technology for optical colonoscopic diagnoses.

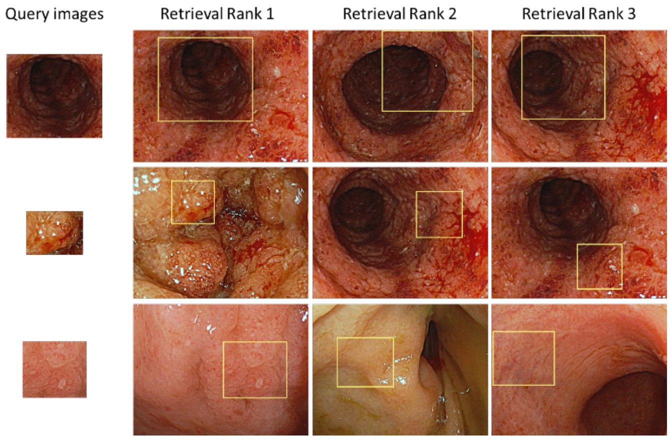

Fig. 7 Top three retrieval rankings for the three query images among the 100 target images.

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