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Improved Diagnosis and Navigation for CT Colonography

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Abstract—**The goal of this research project is to develop a fast, accurate, and patient-friendly computer-aided diagnosis (CAD) component of CT Colonography, that improves the robustness and accuracy of current colon wall segmentation and achieves earlier colorectal cancer diagnoses through an improved polyp detection method.**

Many advanced image processing techniques are applied to clearly outline the colon wall in the CT data set of human abdomen, and subtract the colon portion from the entire data set. After the subtraction, the detailed information and the surface curvature information on the colon wall is analyzed. The active contour model is assisted by presegmentation steps including mathematical mophology filtering, edge detection and other image processing techniques.

I. Introduction

Colorectal carcinoma currently ranks as the second leading cause of cancer-related death and the third most common human malignancy in North America [1]. Unfortunately, colon cancer is most often discovered after the patient develops symptoms, and by then, the likelihood of a cure has diminished substantially. Earlier detection and removal of polyps is the key to prevent colon cancer and can eliminate colon cancer in 90% of patients [2].

The most accurate diagnostic procedure currently available, for detecting polyps is conventional colonoscopy. It is expensive, invasive, uncomfortable, and time consuming, and it carries a small risk of perforation and death. It is not feasible as a population screening test as the number of endoscopists is not sufficient to accommodate a large number of patients. Recently, Computed Tomography Colonography (CT Colonography) has been developed as an alternative method to evaluate the entire colon for polyps [3], which leads to an easier, more comfortable examination than other screening tests.

CT Colonography provides a safe, minimal-invasive approach to detect colonic polyps using medical imaging and 3D software to create virtual endoscopic images of the colonic surface. CT Colonography has been advocated as a technique for providing mass screening for colonrectal carcinoma. It has emerged as a promising alternative procedure, with potentially lower complication rate, improved patient comfort and patient acceptance. However, the accuracy and efficiency of viewing hundreds of axial images per exam are limited by human factors such as attention span and eye fatigue.

CT Colonography is still impractical, mostly due to the following limitations:

1. There are limitations in the accuracy and robustness of current computer aided detection (CAD) techniques for polyp detection, thereby reducing the efficiency of Radiologists in detecting polyps.

2. Current CT Colonography techniques are time consuming. Despite the recent advances in image display technologies, studies show that the case interpretation time is still between 15 – 40 min even when reading is done by experts in abdominal imaging, [4], [5].

As in Conventional Colonoscopy. it is essential that during CT Colonography all colonic mucosal surfaces must be adequately visualized and examined. This includes potential "blind spots" situated behind prominent mucosal folds, especially within redundant, tortuous segments of colon. The colonic wall must be viewed circumferentially. The navigation component of our CAD system provides a complete examination of the colonic wall, including the "blind areas".

II. Background

2.1 Polyp detection

A variety of computer-aided diagnosis (CAD) methods have been developed to improve both the accuracy and the efficiency of lesion detection in CT Colonography.

Vining et al [6] developed a method that measures abnormal wall thicknesses using heuristics. Other approaches have analyzed the morphology of the mucosal surface. Summer, et al [7], [8] have developed a method that uses size, attenuation, and curvatures calculated with convolution-based partial derivatives to find polyps. Software [9], and [10] use a "filter 7" function to detect polyps. A reduction of the number of false-positives was achievable by sampling the CT numbers of each voxel within a possible polyp along a ray directed through the polyp.

Yoshida et al [4], [5] use shape index and curvedness (computed with partial derivatives), directional gradient concentration, and quadratic discriminant analysis using both prone and supine datasets. Kiss et al [11], combined surface normal and sphere fitting methods. In addition, secondary CAD algorithms that are designed to reduce the false-positive

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rate of primary CAD algorithms have been proposed. Gokturk et al [12] applied support vector machines to shape and attenuation features to reduce false-positives and reported a 50% increase in specificity at a sensitivity level. Acar et al [13] have applied edge displacement fields to reduce false-positives and reported a 23% increase in specificity at a constant sensitivity level.

Paik et al [14] employ surface normal overlap method which uses a statistic model of anatomic shapes to simulate CT data to achieve polyp detection. This methodology is able to distinguish between polyps and background anatomy such as haustral folds.

These previously described CAD algorithms have achieved varying levels of accuracy although they all leave room for improvement.

2.2 Viewing System for Blind Spots on CT Colonography

Several investigators have addressed the issue of "unviewed regions" in CT Colonography [14] – [18]. Most recently, Hiyashi et al describe a technique to detect undisplayed regions during fly-through and to perform quantitative evaluation [19]. In this process, the undisplayed regions are detected by marking displayed triangles for surface rendering or displayed voxels for volume rendering. The voxels or triangles without displayed marks are considered to be undisplayed triangles or voxels.

Despite the problems created by blind areas, Cotton et al reported that the incorporation of the fly-through data with the initial axial CT evaluation increased the sensitivity of CT Colonography for the primary outcome (detection of participants with lesions <6 mm) by 17% to 56% but reduced specificity by 5%. For participants with lesions sized at least 10 mm, the fly-through data increased the sensitivity by 12% to 67% and decreased the specificity by 1%.[20] Thus, any methodology that helps ensure that all mucosal surfaces are adequately visualized and examined, including the blind areas, potentially, could simultaneously improve detection rate, as well as serve as an internal quality assurance measure of the technique itself.

A software solution to the problem of "blind areas" or "unviewed regions" in CT Colonography, has been developed in this research as an additional component to polyp detection which helps radiologists examine the complete colon with 100% coverage.

III. METHOD

3.1. Colon lumen detection

A gray scale minima detection using mathematical morphology opening and closing operators [26] is applied to detect the colon lumen from the CT images of abdomen. The lumen of the colon is the darkest feature in the image and can be extracted efficiently. The result of minima detection generates a contour on each colon piece.

3.2. Colon segmentation

Colon wall segmentation is achieved by applying an active contour model with an additional constraint. Level set method [21], [22] was studied and modified to this task to perform colon segmentation.

Level set method for image segmentation has been extensively evaluated over the last few years. Level set method uses a function that depends on the image gradient, as an edge detector to stop the curve evolution [22], [23]. The model can only detect objects defined by gradient. This type of segmentation by using only local information has been often frustrated by poor-contracted regions due to occluding and occluded objects and often enhanced by their use of prior shape information. A model using level set and shape prior has been developed to detect objects occluded in an image [24], [25], [27]. Texture information applied to level set [29] has also been reported and has been explored for polyp detection in this research.

3.3. Colon surface reconstruction and polyp detection

Identifying colonic polyps using CAD is very challenging because polyps occur in various sizes and shapes, the thickened folds, and retained stools may mimic their shape and density. A unique segmentation step is applied to outline the surface of the colon wall.

3.4. An innovative 3-Component Viewing System

(1) Mucosal Coloration

Mucosal Coloration is a technique that provides a simple, automated process that converts the color of unviewed colonic mucosa from one shade or hue to another, as the mucosa is adequately observed. The "blind regions" of colon are those portions of the colon that are difficult to visualize since they are situated behind prominent mucosal folds, especially within redundant, tortuous segments of colon [3]. The unviewed regions remain unchanged in color, enabling the Radiologist to seek and examine these regions after the initial fly-through.

To ensure adequate observation, in this study, as a portion of colonic mucosa is viewed, at a specified distance and angle of view (DAV), it is transformed into a different color (e.g. from yellow-tinted to pink). Thus, any portion of the colonic mucosa that was not viewed in the required field of view would remain yellow-tinted.

(2) Front-and-Side-Viewing Colonoscope

There are two types of endoscopes used by gastroenterologists: forward-viewing scopes and side-viewing scopes. Virtual Colonoscopic Fly-Throughs are

generally displayed as if seen through a forward-viewing endoscope. The “virtual colonoscope", described here is capable of both "front-viewing" for most of the fly-through, as well as "side-viewing" for looking around mucosal folds, at “blind areas”. A unique **Virtual Endoscope** that is capable of Front-Viewing, as well as Side-Viewing will enhance the Radiologist’s ability to examine all colonic mucosal surfaces.

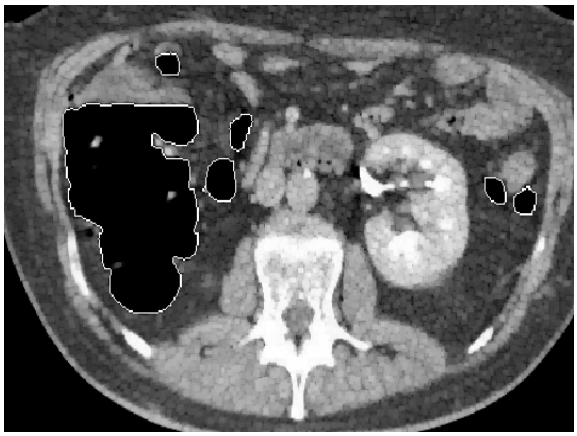
(3) Navigation System

In the Navigational System described here, the circumferential surface of the colon may be divided into 4 quadrants of 90^o. An interactive icon for each quadrant, displaying a small 90^o view, is situated along the border of the virtual endoscopy screen. The normal, front-viewing mode may be converted into a side viewing mode by clicking on the appropriate quadrant icon. By doing so, a 90^o view of the selected segment will be displayed in the main window.

In addition, any segment containing unviewed regions will be high-lighted, flashing, or in some other way emphasized, to alert the viewer that unviewed regions are in the vicinity. (Figure 8) The intensity of the flashing or high-lighting may be intensified the closer one gets to the region, with an additional notification that the region is at 90^o to the endoscope.

IV. Result

We have collected 5 CT data sets of patient abdomen and applied our active contour model [37,38] to segment the colon from the CT images. The model segments the colon wall robustly when the data set is very clean (i.e. no substance inside the colon). The model then is improved by modifying the constraints that provide the texture information along the contour to the model. The texture information is represented by local standard deviation, local mean and local gradients. The results are shown in figures 4 and 5.
The segmentation results are demonstrated in Figure 4 and 5. The surface reconstruction show in figure 6.



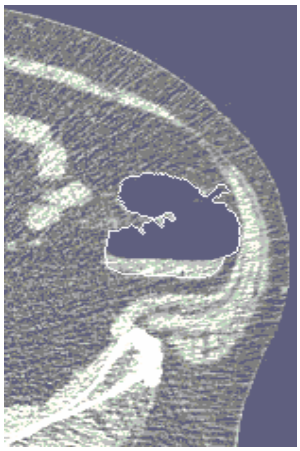


Figure 4 and 5: The results of segmentation using Active contour model. Figure 4: the CT data containing stools inside the colon; Figure 5: the CT data containing liquid substance alone the colon wall.

Figure 6: The surface reconstruction from the segmentation.

V. Summary

This research provides a novel computer-processing methodology for the CAD component that improved the existing CAD system for CT Colonography. The system has provided a robust polyp detection method and a navigation system that unveils the “blinded region” on colon wall of CT Colonography. The method developed in this research also has potentional to provide solutions to other clinical problems.

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