Projection-based features for reducing false positives in computer-aided detection of colonic polyps in CT colonography

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ABSTRACT

A large number of false positives (FPs) generated by computer-aided detection schemes is likely to distract radiologists’ attention and decreases their interpretation efficiency. Therefore, it is desirable to reduce FPs as many as possible to increase the detection specificity while maintaining the high detection sensitivity. In this paper, several features are extracted from the projected images of each initial polyp candidate to differentiate FPs from true positives. These features demonstrate the potential to exclude different types of FPs, like haustral folds, rectal tubes and residue stool by an evaluation using a database of 325 patient studies (from two different institutions) which includes 556 scans at supine and/or prone positions with 347 polyps and masses sized from 5 to 60 mm. For comparison purpose, several well-established features are used to generate a baseline reference. At the by-polyp detection sensitivity level of 96% (no loss of detection sensitivity), the number of FPs per scan is 7.8 by the baseline and 3.75 if the new projection features are added, which is a reduction of 51.9% FPs from the baseline.

Keywords: Colonic polyps, false positive, projection, feature, computer-aided detection, CT colonography.

1. PURPOSE

To reduce false positives (FPs), many researchers applied textural analysis directly in the volume of interest (VOI) to explore the difference of the CT density distributions of the true positives (TPs) and FPs. However, because of the subtle difference in image intensity distribution inside a polyp v.s. its outside surrounding normal tissues, features derived by a voxel-by-voxel fashion inside each VOI have shown limited gain in FP reduction [1]. An implicit operation of projection or line integral through the VOI is expected to enhance the image intensity difference. The usefulness of a single projection image, or so-called electronic biopsy technique, through a suspicious patch has been shown in [2, 3]. For example, a typical polyp larger than 5 mm, including neoplastic and nonneoplastic lesions, would have a uniform concentric ring pattern, with a red core gradually changing to a blue outer ring [3], as shown in Fig. 1(b). According to [3], other colonic objects, e.g., tagged or even untagged stool, impacted diverticula, air bubble artifacts, etc., would have different color patterns.

![Fig. 1. A 10 mm pedunculated tubular adenoma in the ascending colon of a 62 years old female, showing a typical translucency color signature. (a) The 3D endoluminal view of the polyp. (b) Translucency display applied to the 3D image in (a). (c) The 3D endoluminal view of the same polyp, but viewed at another eye position and direction. (d) Translucency display applied to the 3D image in (c).](image)

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The ability of distinguishing TPs from FPs with the above translucency display, as reported in [3], stems from the different CT density distributions in the VOI of TPs and FPs. In Fig. 2, the histograms of five VOIs (retrieved manually with inclusion of four neighboring slices of the concerned slice in the figure for each VOI) are plotted in terms of the CT density values. The plot from a polyp has a peak around 100 HU due to the soft tissue core, while the plots from two stools have a peak located over 300 HU because of the enhancement of the tagging material. The illeocecal valve has a peak around -80 HU owing to the fat tissue. The VOI on the tube has a relative flat histogram, resulting in a flat peak around 180 HU, where many pixels have densities less than -200 HU since the tube is hollow and the VOI includes part of the hollow area. Therefore, we can roughly claim that the CT density distribution pattern is different between TPs and FPs, which explains the reason why the existing texture features have the capability of classifying TPs and FPs. However, most of the existing texture features, like the above mentioned various orders of statistics of the CT densities, might overlook the difference of the distribution patterns. For example, the widely-used feature of the mean of CT densities, a “global” measure, of the VOI of the polyp or the tube in Fig. 2 is 1.7 HU or -10.5 HU respectively. This difference depicted by their histograms (peaked or flattened distribution) is very subtle (i.e., 1.7 vs. -10.5 HU over the variation of one hundred HU) and is less effective to classify FPs and TPs.

![Fig. 2. The histograms (bottom figure) of CT density distribution of five VOIs, which are indicated by the closed red curves on the top five pictures. On the top row from left to right, there are a polyp, two stools (i.e., the stool_1 and stool_2 in the bottom figure), an illeocecal valve and a rectal tube.](image)

In this study, orthogonal projections along three optimal directions (rather than a single arbitrary direction for better description of texture feature) of each IPC are obtained and several effective features are extracted automatically from the projected images to differentiate FPs and TPs. Experiments were designed on a large CT colonography (CTC) database to demonstrate the potential of these new features.

## 2. MATERIALS AND METHODOLOGY

### 2.1 Materials

The performance of the extracted features was evaluated on a CTC database of 325 patient studies, which included 66 from the University of Wisconsin Hospital and Clinics and the rest from the publicly available WRAMC database at http://imaging.nci.nih.gov (by courtesy of Dr. Richard Choi), Virtual Colonoscopy Center, Walter Reed Army Medical Center, Washington, DC. In these cases, the colon cleansing was performed with standard pre-colonoscopy cleansing or barium enema bowel preparation. Single dose of 2% barium (250 ml) and diatrizoate (60 ml) were given to tag residual stool and fluid for the cases from the first institution, while 500 ml barium and 120 ml of Gastrografin for those from the second institution. For both institutions, multi-slice CT scanners (Light Speed Ultra, GE Medical System, Milwaukee WI) were used in helical mode to collect data with collimations of 1.25-5.0 mm, pitch of 1-2, reconstruction interval of
1.25-5.0 mm and the scanning protocol including modulated mAs in the range of 50-200 and kVp in 120-140. Patients from the second institution were scanned in both supine and prone positions, while some of those from the first institution were scanned at an additional lateral position. Among all of these scans, some of them were inadequately distended or some had severe artifacts and, therefore, were excluded from the performance evaluation study. As a result, there were 556 scans altogether, of which 258 scans had polyps and the remaining 298 had no polyp. Assuming that one polyp in different scans was counted as different polyps, there were 347 clinically significant polyps and masses confirmed by both OC and VC. The size distribution of the polyps and masses is shown in Fig. 3, where 64% (222/347) of the polyps are less than 10 mm. The evaluations were conducted in two polyp size categories of clinical importance: ≥ 10 mm (125 including 4 masses larger than 30 mm) and between 5 and 9 mm (222). Polyps smaller than 5 mm are beyond the interest of this study. For short, the term polyp in the following text refers to both polyp and mass.

![Fig. 3. The size distribution of the 347 lesions in the CTC database.](image)

### 2.2 Overview of the CADpolyp scheme

The whole CADpolyp scheme is shown in Fig. 4. The extraction of the VOI of each initial polyp candidates (IPCs) was detailed in our previous work [1]. With the VOIs, we first set up the local reference frame (LRF), the three optimized directions, and then apply two different projection schemes to get gray and color 2D projection images, based on which we extract the new features. All the features are finally sent to a support vector machine (SVM) classifier to classify the TPs and FPs [1]. In this study, we focus on the extraction process of the new features.

![Fig. 4. The pipeline of the presented new method.](image)

### 2.3 The local reference frame (LRF)

With the translucency tool [3], different viewing directions lead to different patterns in the projected image. As shown in Fig. 1(d), the red core expands and the blue boundary does not close as compared to that in Fig. 1(b). In this study, we define the normal direction first, along which the height of the polyp candidate is measured. Through observation, we notice that directions close to the normal of a polyp would be very meaningful, such as the viewing direction in Fig. 1(a) and 1(b) which are close to the normal of the polyp. Such direction $\vec{N}$ can be approximated by

$$\vec{N}(C) = \sum_{p \in Seed(C)} SI(p_i) \cdot \vec{n}(p_i) / \sum_{p \in Seed(C)} SI(p_i)$$  \hspace{1cm} (1)

where $C$ represents the IPC under consideration. $Seed(C)$ is the set of seed voxels of the IPC [1]. $SI(p_i)$ and $\vec{n}(p_i)$ denote the shape index and the unit image gradient at voxel $p_i$. The blue arrow in Fig. 5(a) shows the normal direction which is extracted from the polyp in Fig. 1(a).
Fig. 5. Defining the LRF for an IPC. (a) The blue arrow represents the normal direction of the IPC, starting from a yellow small ball centered at the centroid of the VOI. The cyan rectangle through the centroid of the VOI denotes the plane perpendicular to the normal direction. (b) Extraction of the optimized 2D frame (the dotted arrows) of a point set (the blue points mimicking the results of projecting the VOI to the cyan surface in (a)). The solid arrows represent an arbitrarily selected initial frame. (c) The resulted LRF of the IPC in (a). (d) The sub-volume (the yellow box) of the IPC in (a).

The other two orthogonal directions perpendicular to the normal direction can be optimized by using the principal component analysis [4] on the 2D projection of the VOI, as shown in Fig. 5(b). Fig. 5(c) shows the final LRF of the 10 mm polyp in Fig. 1(a). We refer to the three directions of the LRF as axial (the blue arrow), sagittal (the red arrow) and coronal (the green arrow) directions, and the relative projection surfaces as axial, sagittal and coronal surfaces (Fig. 5(d)). In the LRF, the bounding box of the VOI forms a sub-volume (Fig. 5(d)) to do the successive projection procedure.

2.4 Projection

After determining in the LRF of each IPC, the sub-volume is orthogonally projected onto the axial, sagittal and coronal surfaces, and the projected images are called axial, sagittal and coronal images in following text. The projection process can be illustrated by Fig. 6. The generated 2D images on the axial, sagittal and coronal surfaces are called the axial, sagittal and coronal images respectively, as shown in Fig. 10. In this study, to evaluate the pixel values of the projection image, two integration schemes are employed along each projection ray: (1) the CT intensities at all the sample points are simply accumulated; and (2) the CT intensity at a sample point is encoded into a color with the color mapping scheme in [3], and then all the colors are integrated based on a weighting strategy

\[
i_j(x + 1) = (1 - o_j(x + 1))i_d(x) + o_j(x + 1)*i_s(x + 1)
\]

where \(i\) varies among the red, green, blue and white color channels, and \(o\) represents the opacity value serving as the weight in the iteration process. The subscripts \(d\) and \(s\) indicate the destination and source colors.

Fig. 6. Illustration of the projection procedure. (a) The projection rays (red arrows) shoot down through the 3D object (the middle polypoid object), and are collected on the projection plane to form a 2D projection image (the bottom image) with one ray corresponded to one pixel (indicated by the dotted red line). (b) Points are evenly sampled on each projection ray.
Together with the above weighted line-integral scheme, the differences of CT density values of various material types are explored with the proven transfer function in [3]. To make a self-contained presentation, we quote the plot of the transfer function in [3] as shown in Fig. 7. With the function, the green and blue channels monotonically increased with the CT densities in the ranges of [-436, -16] (covering all the fat tissue) and [-920, -128] HU (covering all the lumen), and were zeroed elsewhere. The red and white channels were assigned non-zero values only for CT densities larger than -64 HU (including all the soft tissue and bone/tagging material) and 200 HU (covering all the bone/tagging material) respectively. The opacity varied in the range of [0, 0.35] as a piecewise linear function of the CT densities. As a result, a projection ray dominated by soft tissue, lumen, fat tissue or tagging material/bone will lead to a red, blue, green or white pixel respectively in the projection image.

![Figure 7](image-url)

**Fig. 7.** The plot of the transfer function, where the red, green and blue curves indicate the mapping of the three channels. The white channel is shown with the gray curve, and the black curve plots the opacity values according to attenuation (HU).

By applying the MAP-EM segmentation algorithm [5, 6], we get the cleansed CTC volumes with the tagged fluid removed. Column 1 in Fig. 8 shows the un-cleansed and cleansed axial slices around a TP finding. After applying the above two projection schemes to the un-cleansed and cleansed CTC volume, the axial gray and color projection images are shown in the right two columns in Fig. 8. As can be seen, the MAP-EM segmentation algorithm removes the residue fluid and exposes the polypoid shape more conspicuous than the un-cleansed one. In this study, we apply the two projection schemes to the cleansed volumes. The generated images are gray with the first scheme (columns 3 to 5 in Fig. 9), but colorful with the second (last column in Fig. 9).

![Figure 8](image-url)

**Fig. 8.** The axial projection images (last two columns) of a 10 mm polyp based on the original (upper row) and cleansed (bottom row) CTC images. The red arrows in the left column indicate the IPC findings.
Fig. 9. The projection results of several typical IPCs (generated with the method in [2]). Each row indicates one IPC. Column 1 shows the uncleansed CT images (axial or sagittal slices) with the red arrows pointing at the IPCs. Column 2 shows the LRF. Columns 3 to 5 show the projected axial, sagittal and coronal gray images, and the last column shows the axial color image. True polyps in rows 1 to 3 are 10 (same as in Fig. 1), 9 and 6 mm respectively. FPs in rows 4 to 6 are three tagged stool, while rows from 7 to 9 are a tube, a thickened fold and a round ileocecal valve.
2.5 Feature extraction

As shown in Fig. 9, the sub-volumes of TPs typically are kind of cubic due to their round shape, but those of FPs due to rectal tubes and long folds have a much larger size in one direction of the LRF. Therefore, a morphological feature, named as *axis-ratio*, can be designed to indicate the ratio of the minimum and maximum sizes of the sub-volume in the three directions of the LRF.

![Highlighted, bright, and gray patches](image)

**Fig. 10.** Illustration of the projection images of the 3D polypoid object in Fig. 6, where the red arrows indicate the characterizing patches. (a) The axial image. (b) The sagittal image. (c) The coronal image.

From three directions of LRF, the projected 2D gray images show characterizing patterns. Fig. 10 illustrates the three projection images of the polypoid object in Fig. 6. For the axial image, on the rays around the central part of the projection plane, there are more sample points having higher intensities due to soft tissue than those around other parts where there are more lumen sample points. This leads to a highlighted disk-like patch (or simply highlighted patch) in the center area of the image. As for the sagittal and coronal images, rays going through the outer part (the peak) of the polypoid object have less high intensity points than those going through the base where the object is sitting on. Therefore, a gray and a bright patch are visible in the images. Furthermore, the gray patch often locates at the mid-top in the sagittal image and at the mid-right in the coronal image. The bright patch usually locates at the bottom in the sagittal image and at the left in the coronal one. Such pattern characteristics can be observed in the gray images of polypoid IPCs (rows 1 to 6 and row 9 in Fig. 9), but are not available in the images of the FPs, e.g., the fold (row 8 in Fig. 9), and the rectal tube (row 7 in Fig. 9). Based on the above observations, we build up features from the three gray projected images.

<table>
<thead>
<tr>
<th>Features</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing features</strong></td>
<td>mean(SI), var(SI)</td>
</tr>
<tr>
<td></td>
<td>var(CV), var(CT)</td>
</tr>
<tr>
<td><strong>New features</strong></td>
<td>AR</td>
</tr>
<tr>
<td></td>
<td>HR, DL</td>
</tr>
<tr>
<td></td>
<td>LRC, LRS</td>
</tr>
<tr>
<td>POSy(L)·POSy(L)·POSy(B)·POSy(B)</td>
<td>The normalized positions of the light and bright patches in the coronal and sagittal images.</td>
</tr>
<tr>
<td>POSx(L)·POSx(L)·POSx(B)·POSx(B)</td>
<td>The three components of the dominant color of the core area in the axial color image.</td>
</tr>
</tbody>
</table>

In gray axial images, after determining the highlighted patch, features, i.e., the *highlighting ratio* and *disk-likeness*, are extracted. The highlighting ratio is defined by the ratio of the mean intensity of the highlighted patch and its surrounding area to depict how much the patch is highlighted. Meanwhile, the disk-likeness depicts the morphological characteristic of the disk-like highlighted patches of TPs.
In the sagittal/coronal images, the ratio of the mean intensity of the gray patch and bright patch is reflected by a feature named as the *lightness ratio*. Additionally, as mentioned above, the location of the gray and bright patches can also be used to characterize TPs and, therefore, the normalized positions of the centroids of the gray and bright patches are chosen as the corresponding features.

The last column in Fig. 9 shows the projected axial color images of some IPCs. Typically, the dominant soft tissue inside true polyps (rows 1 to 3 in Fig. 9) gives rise to red cores, which are enclosed by blue rings due to the tissue-lumen interface, in the axial projection images. The rows 4 to 6 in Fig. 9 show the typical patterns of tagged stool, which give the white-dominant cores in the color image due to the tagged material distribution all over the stool. The color images in rows 7 and 8 in Fig. 9 show two other common FPs in CADpolyp systems, i.e., a rectal tube and a fold. For these IPCs, the soft tissue and pseudo-soft tissue voxels in the fold and the tube lead to red patches in their corresponding color images. Fortunately, such kind of IPCs can be excluded by their large axis-ratio values. The ileocecal valve mimics big polyps, and is a common source of FPs both for radiologists’ inspection and CADpolyp systems. However, the characteristic fat tissue in the valve leads to green pixels in the core area (row 9 column 6 of Fig. 9), and this color pattern is not available in the color images of the true polyps. Therefore, the red-dominant core in the color axial image is a meaningful signature of true polyps against that of the stool, ileocecal valves, colon folds and rectal tubes. The signature is explored by three features, named the *dominant color* in this study, describing the color distribution with the three color components.

In order to evaluate the potential of the new features, four well established existing features are used as reference in this study. Therefore, all 20 features are listed in Table 1.

### 3. RESULTS

After using the method in [1] for all the 556 scans, 11,047 IPCs were generated including all the 347 TPs. 5,580 IPCs were randomly selected including 180 TPs and 5,400 FPs to form the training set, and the rest 5,467 IPCs (167/5,300 TPs/FPs) formed the testing set. The ratio between the number of FPs and that of TPs was about 30. A 10 folds leave-one-out cross-validation was employed in the SVM training process to seek for an unbiased training process. Three parameters were exhausted through a 3D grid-search procedure, which was detailed in [1]. Based on such training and testing set, two experiments were conducted: (1) only the four existing features were used; (2) all the 20 features were input to the SVM classifier. The testing results were plotted together using the fROC curves for comparison in Fig. 11.

![fROC curves](image)

*Fig. 11. The fROC curves of the two experiments of using the 4 existing features only (green), and all of them together (red) in the SVM classification.*
In overall, the second experiment performed consistently better than the first one at all the sensitivity levels. At the detection sensitivity level of 96%, the two experiments yielded the FP rates at 7.8 and 3.75 FPs per scan respectively based on the assumption of 275 scans forming the testing set.

4. CONCLUSION

In conclusion, based on the projected 2D images, we have extracted several characteristic features towards increasing the detection specificity of our CADpolyp pipeline. From the experiments on a CTC database including 556 CTC scans with 347 TPs, these features were evidenced to have the potential to remove FP findings dramatically. At the by-polyp detection sensitivity level of 96% (no loss of detection sensitivity), the number of FPs per scan was reduced to 3.75 if the new features were added from 7.8 if only four existing features were used. This is an additional 51.9% FP reduction. We argue that this evaluation is statistically meaningful since our CTC database is rather large and comes from two different institutions.

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