

## 3D COLONIC POLYP DETECTION IN CT IMAGES USING TEMPLATE MATCHING

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### ABSTRACT

*In this paper we present a computer aided detection (CAD) system for colonic polyp detection in computed tomography (CT) images. Here, the segmentation of the colon region was performed in three steps which are thresholding, labeling and analyzing the shape morphologies using decision rules. After extracting the colon region, searching with 3D semi-spherical polyp template was performed to detect the polyps. Because the polyps can appear in all possible orientations on the colon wall, 3D rotations were performed during the search. The similarity was measured using convolution operation. The performance of the system was evaluated using a test set containing 20 cases having 13 polyps which were marked by expert radiologists. When the results were compared with the reviews of the radiologists, it was seen that the system achieved 92.3% sensitivity with 0.84 FP regions per polyp.*

**Keywords:** : Computer aided detection, colonic polyp detection, colon segmentation, template matching.

### 1. INTRODUCTION

Colorectal cancer is the second leading cause of cancer in industrial western countries and the third most frequently diagnosed cancer worldwide [1]. Most colon cancers begin as polyp that grows from the mucosal surface of the colon and it takes about 10 years for a polyp to develop into cancer [2]. Clinical investigation has shown that early detection and removal of polyps can prevent the disease from reaching its deadly stage. This highlights the importance of effective screening procedures for the vast asymptomatic patient population [3]. Computed tomography colonoscopy (CTC), also referred as virtual colonoscopy (VC), has become a widely used technology in clinical trials. Radiologists use 3-dimensional (3D) visualization programs for primary CTC interpretation or as a secondary problem solver when ambiguity on primary 2-

dimensional (2D) reading needs to be resolved. However, with increasing resolution of the latest scanners and the rapidly growing amount of data requiring visual inspection, the demand for computer aided detection (CAD) becomes stronger than ever. Detecting polyps using the virtual colonoscopy technology is not so easy since many other objects such as colon folds and residual materials have similar shapes and intensity patterns as those of polyps. Therefore, automatic polyp detection is one of the keys to the further success of the virtual colonoscopy technology [4].

A large number of such schemes are proposed in the literature. Vining et al. [5] used abnormal colon wall thickness to detect colonic polyps. Their method achieved 73% sensitivity with 9 to 90 false positives (FP)/dataset. Summers et al.

[6] used the mean, the Gaussian and the principal curvatures of the colon surface and showed good preliminary results for phantom and patient data. The sensitivity of their technique varied between 29% to 100% with 6 to 20 false positives per dataset. Kiss et al. [7] used surface normals along with sphere fitting to produce 85% polyp sensitivity for polyps larger than 6mm with 2.82 FP/dataset. Yoshida et al. [8] developed a technique that uses features such as the shape index and local curvature calculated from small volumes of interest that were used as inputs for a fuzzy clustering in order to discriminate between polyps and folds. They reported 89% sensitivity with 2 false positives (FP) per dataset. Paik et al. [9] proposed a different approach for polyp identification where they evaluated the local convexity of the colonic wall using the normal intersection. This method was efficient to detect polyps but the level of false positives was high.

This paper is organized as; in Section 2, rule based segmentation of colon region and polyp detection using 3D template matching are described. In Section 3, results are given and are analyzed. Finally, Section 4 concludes the paper.

## 2. MATERIALS AND METHODS

In CT colonoscopy, a fold or a residue stool can appear like a polyp and many folds have a similar diameter to the lesions of interest. If the CAD systems detect the candidates based on 2D image features hundreds of candidates occur. Then the systems employ various operations to tackle the enormous numbers of false positives

and to filter the large volume of false positives, the true positives are also extracted. The experienced radiologists look for colonic polyps not by considering individual image slices independently, but by searching through the serial images for 3D appearance characteristics that distinguish polyps from folds.

The technique carried out in this study resembles the ways a radiologist attempts to search for a polyp in a colon dataset. A radiologist first identifies the colon lumen by concentrating on the regions that are filled with air and fall under the category of colon lumen based on anatomical knowledge. Then the radiologist looks for any object that appears as a raised structure grown from the colon wall into the lumen and evaluates the connectivity between the identified regions while traversing through the slices. The next move will involve concentrating on the region of interest to classify it as being a polyp or other polyp-like structure.

This paper provides an efficient technique for automatic detection of polyps. It consists of two stages, colon segmentation and polyp detection. The colon segmentation is carried out by combining the methods thresholding, connected component labeling and eliminating the undesired shapes by analyzing their morphological structures. After colon segmentation, searching for any raised structure from the colon wall was performed using a semi-spherical 3D polyp template. The flowchart of our method is illustrated in Figure 1.

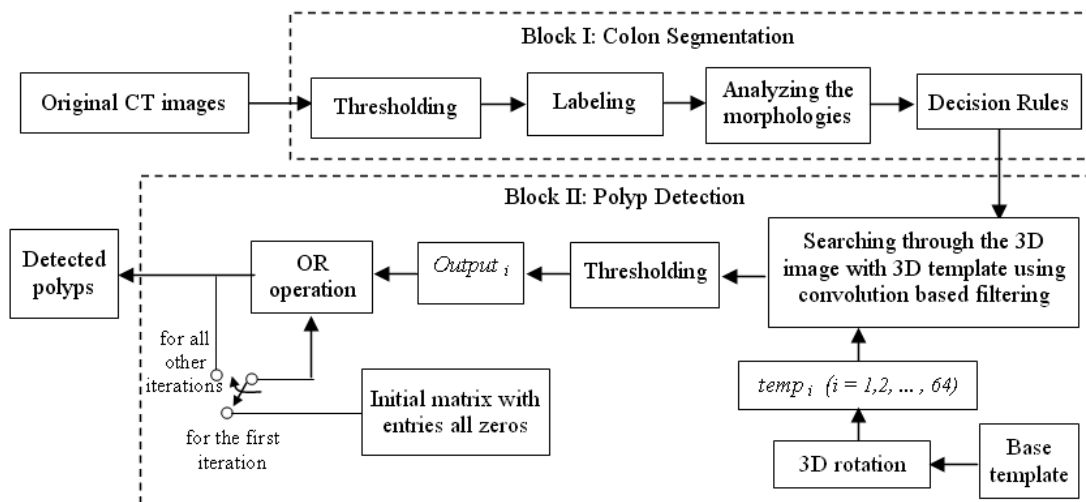


Figure 1. Procedural flowchart for detecting colonic polyps.

For the development and evaluation of the proposed system we used the dataset provided by the Virtual Colonoscopy Center of Walter Reed Army Medical Center (WRAMC), National Institutes of Health, USA [10]. The data sets originally consisted of 400–480 slice images in a 512×512 matrix. These 2D slices have 1.25 mm thickness and each slice consists of unit elements called as voxels having values due to the thickness of the slice. Hounsfield Unit (HU) is a unit of x-ray attenuation used for CT scans, each voxel being assigned a value on a scale on which air is -1000, water is 0, and compact bone is +1000 [11]. The imaging range of the data was from the diaphragm to the rectum so that the entire colon was included in the volume data.

## 2.1. RULE-BASED COLON REGION SEGMENTATION

There are two problems which make colon segmentation a difficult task. Firstly, the colon is not the only gas-filled structure in the abdomen. Secondly, obstructions such as peristalsis, very large lesions, and residual feces in the colon complicate automated segmentation and prevent a continuous colon segment, therefore the use of multiple manually placed seed points is required. Such obstructions require a time-consuming manual placement of seeds which increase the likelihood of an incomplete segmentation [12].

Contrast enhancement fluid (CEF) assists the segmentation of intra-luminal materials from soft tissues (computed cleansing). It potentially allows a less strict colon preparation as well [13, 14]. Preparation of the bowel is essential to produce optimal VC results. Removal of the bulk of feces with colonic lavage is important in providing a high contrast interface at the colon wall. Gas insufflation with CO<sub>2</sub> or room air is required to distend the colon, filling the lumen therefore providing a high contrast gas/tissue interface. However, some residual feces usually remains in bowl shaped regions of the lumen. The retained feces can obscure polyps, obstruct visualization of the colon, and simulate polyps or lesions. Complete removal of retained feces is impractical using only colonic lavage, thus, a way to differentiate between feces and tissue is required. For this reason, in bowel preparation, the patient can be placed on a liquid diet prior to the VC procedure and a colonic lavage to liquefy the fecal stream. An oral contrast agent is given hours prior to the exam to make any retained

fluid radio-opaque. After gas insufflation, the colon is primarily filled with gas and any retained material is a homogeneous CEF. After bowel preparation, CT scout images are acquired to locate the bounds of the colon prior to full resolution helical CT scanning [13, 14].

We developed a rule based colon segmentation method. Here are the steps of colon region segmentation:

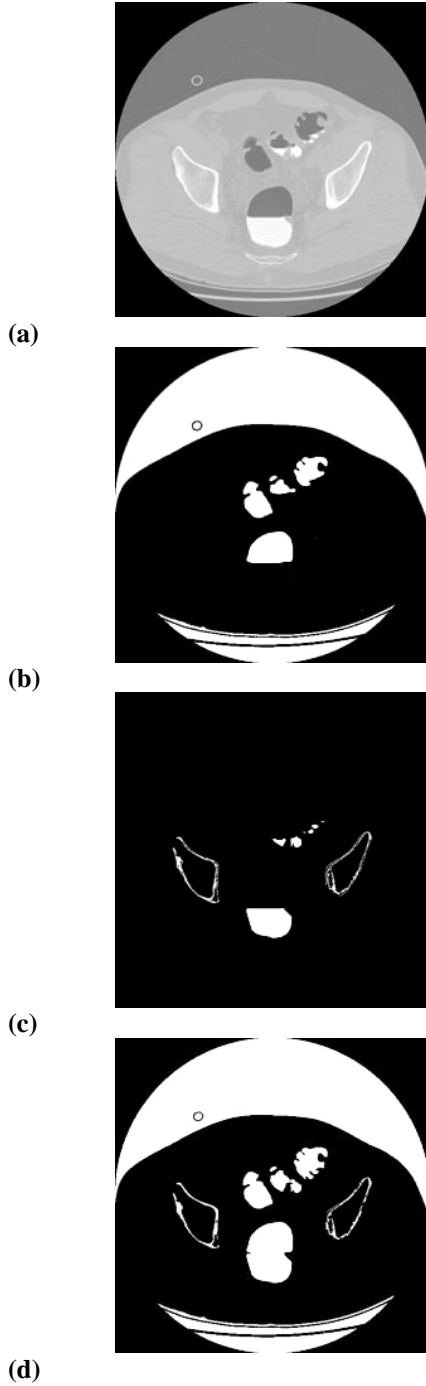
**Step 1: Thresholding.** The first step is performed with predefined air thresholds  $T_{airmin}$  (-10 HU) and  $T_{airmax}$  (750 HU), and fluid thresholds  $T_{fluidmin}$  (1700 HU) and  $T_{fluidmax}$  (2100 HU). Pixels with intensities between  $T_{airmin}$  and  $T_{airmax}$  were labeled as air; those with intensities between  $T_{fluidmin}$  and  $T_{fluidmax}$  as fluid; and all others were removed. The original 2D CT slice is seen in Figure 2a. The pixels with intensities between  $T_{airmin}$  and  $T_{airmax}$ , and between  $T_{fluidmin}$  and  $T_{fluidmax}$  are seen in Figure 2b and 2c respectively. Figure 2d shows the result of the thresholding.

**Step 2: Labeling.** To remove the structures which are not in the colon region, in step 2 labeling was performed. Connected component labeling (CCL) was used to label all structures seen in Figure 2d.

CCL works by scanning an image, pixel by pixel (from top to bottom and left to right) in order to identify connected pixel regions - *i.e.* regions of adjacent pixels which share the same set of intensity values  $V$  [15]. The CCL operator scans the image by moving along a row until it comes to a point  $p$  (where  $p$  denotes the pixel to be labeled at any stage in the scanning process) for which  $V=\{1\}$ . When this is true, it examines the four of the neighbours of  $p$  which have already been encountered in the scan (*i.e.* the neighbours (i) to the left of  $p$ , (ii) above it, and (iii) and (iv) the two upper diagonal terms). Based on this information, the labeling of  $p$  occurs as follows [16,17]:

- if all four neighbours are 0, assign a new label to  $p$ , else
- if only one neighbour has  $V=\{1\}$ , assign its label to  $p$ , else
- if one or more of the neighbours have  $V=\{1\}$ , assign one of the labels to  $p$  and make a note of the equivalences.

After completing the scan, the equivalent label pairs are sorted into equivalence classes and a unique label is assigned to each class. As a final step, a second scan is made through the image, during which each label is replaced by the label assigned to its equivalence classes.



(e)

**Figure 2.** (a) The original CT image, (b) the pixels labeled as air, (c) the pixels labeled as fluid, (d) the result of thresholding, (e) the segmented colon region.

**Step 3: Colon region extraction.** To extract the colon region, all white shapes were labeled using CCL in step 2 and in this step their morphologies were analyzed in 3 sub steps. In the first sub step to remove the small shapes, the width of each shape was calculated. As seen in Figure 2d the aspect ratio of the colon region is smaller than the aspect ratio of the most other shapes. Thus in the second sub step aspect ratios of the shapes were analyzed and the shapes with bigger ratios were removed. And finally in the third sub step to remove the shapes with no interior as seen in Figure 3, the coordinates  $(x_c, y_c, z)$  of the center point of each shape were calculated using (1). Then each pixel on the center line was examined. The white and black pixels on the center line were counted. The morphologies of the shapes were analyzed combining the above three sub steps as follows:

$$\text{if } AR(k) > 1.4 \quad \text{or} \quad W(k) < 10 \text{ pixels} \quad \text{or} \quad BWR(k) > 0.2 \quad \text{then} \quad I(x, y, z) = 0$$

where  $AR(k)$  represents the aspect ratio of  $k$ th shape which is the ratio of height to width,  $W(k)$  represents the width of  $k$ th shape,  $BWR(k)$  represents the ratio of the total number of black pixels to the total number of pixels on the center line of the  $k$ th shape and  $I(x, y, z)$  represents the pixel of  $k$ th shape of the image with coordinates  $(x, y, z)$ . With this rule the shapes, whose aspect ratios were greater than 1.4 or whose width was less than 10 pixels or whose ratio of black pixels to total number of pixels in the center line was greater than 0.2, were eliminated and thus the colon region was extracted.

$$x_c = x_{\min} + \frac{x_{\max} - x_{\min}}{2}, \quad y_c = y_{\min} + \frac{y_{\max} - y_{\min}}{2} \quad (1)$$

At the end of the third step the colon region of Figure 2a was segmented as Figure 2e. All of the 2D segmented colon region images were combined, so the 3D colon region image was obtained.

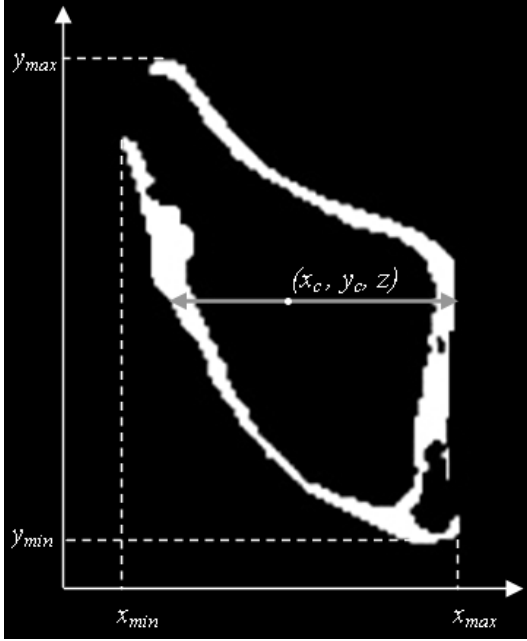


Figure 3. The shape with no interior.

### 2.2. POLYP DETECTION USING A 3D TEMPLATE

In this study, we construct a 3D model, which extracts the imaging features of a polyp and then performs a search through the 3D region of segmented colon images for objects that are similar to our 3D semi-spherical polyp template. For a 3D semi-spherical polyp template having a diameter size 10 pixels, the 5 layers with 10 x 10 pixels are given below in (2)-(6),

$$t(1) = \begin{bmatrix} -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \end{bmatrix} \quad (2)$$

$$t(2) = \begin{bmatrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix} \quad (3)$$

$$t(3) = \begin{bmatrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix} \quad (4)$$

$$t(4) = \begin{bmatrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix} \quad (5)$$

$$t(5) = \begin{bmatrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix} \quad (6)$$

In 3D CT volumes, polyps appear in all possible orientations on the colon wall. Thus while searching through the 3D region of segmented colon volume, the 3D polyp template was rotated in 3 dimensions with 90° and the similarity was measured using 3D convolutions. The rotation of the 3D template was performed using Euler

angles rotation matrices which were developed by Leonhard Euler and explained below.

A rotation of  $\psi$  radians about the x-axis is defined in (7).

$$R_x(\psi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \psi & -\sin \psi \\ 0 & \sin \psi & \cos \psi \end{bmatrix} \quad (7)$$

Similarly, a rotation of  $\theta$  radians about the y-axis is defined in (8).

$$R_y(\theta) = \begin{bmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{bmatrix} \quad (8)$$

Finally, a rotation of  $\phi$  radians about the z-axis is defined in (9).

$$R_z(\phi) = \begin{bmatrix} \cos \phi & -\sin \phi & 0 \\ \sin \phi & \cos \phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (9)$$

The angles  $\psi$ ,  $\theta$  and  $\phi$  are the Euler angles. In this document, we will rotate first about the x-axis, then the y-axis, and finally the z-axis. Such a sequence of rotations can be represented as the matrix product in (10).

$$R = R_z(\phi)R_y(\theta)R_x(\psi) \quad (10)$$

Let  $\mathbf{t}$  be a 3D template matrix and let  $\mathbf{t}(z)$  be the  $z^{\text{th}}$  layer of  $\mathbf{t}$ . The classification task was performed by convolving the 3D segmented colon region image with our 3D polyp model that we call 3D template. The 3D convolution is given below,

$$\begin{aligned} c(x, y, z) &= r(x, y, z) * t(x, y, z) \\ &= \sum_{m=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} r(k, l, m) t(x-k, y-l, z-m) \end{aligned} \quad (11)$$

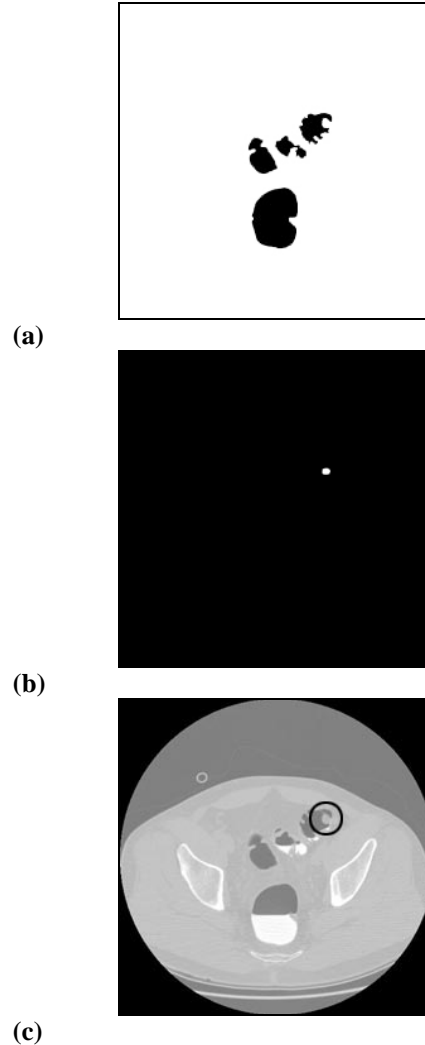
where  $r(x, y, z) \in \{0, 1\}$  is the value of the pixel in  $(x, y)$  coordinate of the  $z^{\text{th}}$  segmented colon image.  $t(x, y, z)$  is the pixel value of the template at the location of  $x$ ,  $y$ , and  $z$ , and  $c(x, y, z)$  is the pixel value of the output 3D images, which is obtained by convolving the 3D segmented colon image with the template, at the location of  $x$ ,  $y$ , and  $z$ .

The shapes, which are similar to the template, become stronger at the end of the convolution computation. Therefore, the pixel values of these shapes become high positive, while the pixel values of non-similar ones become high negative. Thus, to extract the colonic polyps from the output image  $\mathbf{c}$ , we pass the convolution

result from a threshold ( $T_{conv}$ ) that yields a similarity:

if  $c(x, y, z) > T_{conv}$  then  
 $c(x, y, z)$  is a part of the polyp  
else  
 $c(x, y, z)$  is not a polyp  
end.

After applying 3D convolution on segmented colon region seen in Figure 4a, the resultant images given in Figure 4b and 4c were extracted.



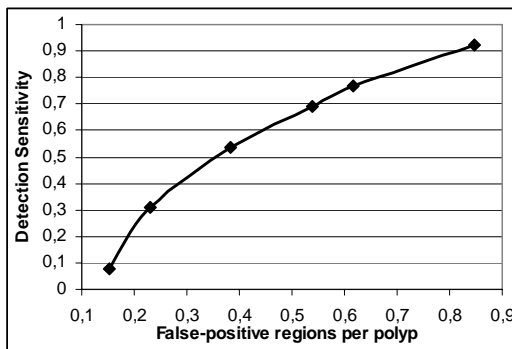
**Figure 4.** (a) The segmented colon region, (b) the detected polyp, (c) the detected polyp on the original CT image.

### 3. RESULTS

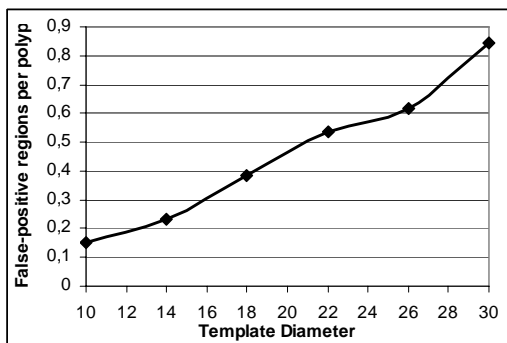
The proposed method was applied to a subset of 20 cases from the WRAMC dataset from which 13 polyps were marked by expert radiologists and confirmed by optical colonoscopy. The polyp sizes were between 10 – 22 mm. The

complete WRAMC dataset comprises many more images, but unfortunately ground truth is provided as a distance from rectum along the colon centerline only, and the precise location of polyps in this dataset must still be carried out by an expert.

Detection sensitivity was calculated according to the diameter of the template. If a large value is chosen as the template diameter, then the probability of detecting the polyp is very high but the number of false positive regions per polyp is also high. If a template with smaller diameter is used, then the probability of detecting the polyp decreases because big polyps are missed, but the number of false positive regions per polyp is small. In Figure 5 and Figure 6, detection sensitivity and polyp diameter are drawn according to false positive regions per polyp. 92.3% of sensitivity was reached at 0.84 FP regions per polyp using a template whose diameter is 30 pixels.



**Figure 5.** Free-response receiver operating characteristic curve showing the performance of the polyp detection task.



**Figure 6.** False-positive regions per polyp versus template diameter.

## 4. CONCLUSIONS

In this paper, we designed a 3D CAD system for colonic polyp detection in serial CT images. A rule based algorithm was used to segment the colon region. This segmentation algorithm was performed in three steps which were thresholding, labeling and decision rules. Using the decision rules the regions out of the colon region were removed. Detection of the colonic polyps was performed using a 3D template. 3D rotating the template, convolving it with colon region volume and using thresholding the polyps were detected successfully. WRAMC dataset was used in this study. 92.3% of sensitivity can be reached at 0.84 FP regions per polyp. We developed a CAD scheme by computer programs that could prepare quantitative values and the position of colonic polyp to radiologists by the virtual colonoscopy. If radiologists take into account the information obtained from our CAD system, their diagnostic performance would be higher and time consuming would be less.

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