A Review of Current Computer Aided Diagnosis Systems for Polyp Detection in Virtual Colonoscopy

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Abstract — **The potential of Computer Aided Diagnosis (CAD) has been exploited lately in order to assist the doctors in carrying out the inspection of lengthy videos from virtual colonoscopy. Colonic polyps are known precursors of the colon cancer, which has been the third mostly diagnosed form of cancer. In this paper, we discuss the most important parameters used for evaluation of CAD systems for polyp detection and outline the recent work which has been done in this area. We present a performance comparison of the recent, well known methods and highlight their importance in envisioning a CAD system fully capable of screening population to identify the people who have higher potentials to be diagnosed with colonic cancer in their lifetime.**

Index Terms— virtual colonoscopy, computer-aided diagnosis, optical colonoscopy

I. INTRODUCTION

Colonic cancer is amongst one of the leading causes of deaths from cancer in the western world [1]. Important predecessors of this type of cancer are colonic polyps, which are benign growths along the colon lining. Most colorectal cancers are believed to arise from these growths which develop slowly over the course of many years. In this context, their early detection and removal can significantly reduce the risk of a patient to be a prospective victim of colon cancer. Therefore, the medical communities around the world have favored the need of screening programs to be run over the entire population in the areas where the people are exposed to threats from this deadly disease.

This fact has given rise to a number of methods, which have since long been used to screen the patients for potential development of colon cancer. The most common manual method which has been used for polyp detection is optical colonoscopy (OC). This procedure involves a visual analysis of the internal walls of the colon and therefore provides an opportunity for the removal of suspected lesions. A microscopic analysis of these lesions can then be conducted to determine if they are precancerous or not. However, most of the people are hesitant to undergo this examination because of the discomfort and inconvenience involved in the procedure of OC.

For this purpose, scientists have been working on the development of non-invasive methods of screening the colon walls for locating any suspicious polyps. Virtual colonoscopy (VC) is a minimally-invasive method, which causes much less discomfort to the patients as compared to the conventional optical colonoscopy [2, 3]. VC exploits the computers to reconstruct the 3D model of the colon. A flythrough of this model can be manually examined by the doctors to identify any suspicious polyps.

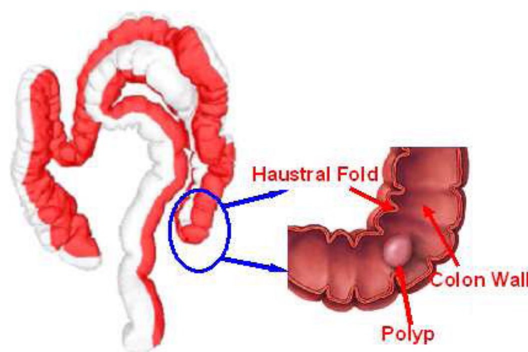

Fig. 1. Three issues in polyp detection, polyp: Dome-like structures, folds: ridge-like structures and colon wall: flat structures

Although it is very convenient for the patient to undergo VC, the procedure produces videos of much longer lengths and it is very time consuming to analyze them which makes it very unattractive for large-scale screening. Besides, the complex structure of the colon surface makes the analysis very difficult and in some specific cases, there is a lack of reproducibility of the diagnosis. The manual observation of VC videos is also influenced by the expertise of the physicians. This motivates the computer scientists to develop computer-aided diagnosis (CAD) methods, which can pre-detect and highlight the polyps in order to reduce the examination time, cost and improve the consistency of the

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results. However, this task is very challenging as the polyps can be in different sizes and shapes. The aim of such CAD systems is the identification of true polyps and removing the false positives. CAD of polyps is a difficult task given that these systems should have the capability of distinguishing between three structures as shown in Fig. 1.

The outline of the papers is as follows: In Section II, we discuss the measures which are used to benchmark the CAD methods for polyp detection, Section III covers the main methods used in different CAD schemes, Section IV discusses the performance achieved by these methods. Section V concludes the paper.

II. PERFORMANCE MEASURES

A variety of CAD algorithms have been developed to improve the accuracy and efficiency of lesion detection. These algorithms are evaluated in terms of the following performance measures:

A. Sensitivity

While doing polyp detection, a careful analysis needs to be carried out and the CAD algorithms should be sensitive enough to highlight very small suspected polyps i.e., it should be able to identify all true positives (100% sensitivity). Therefore sensitivity is considered as one of the performance measures for evaluating the CAD algorithms for polyp detection. This parameter also controls the minimum size of the polyps, which can be detected by a specific algorithm. More sensitive algorithms have a higher potential of detecting the polyps of small sizes.

B. Specificity

The second important measure used for evaluating the CAD algorithms is the specificity i.e., the number of false positives (FP). Ideally, a CAD system should fail at all FP detections (100% specificity). There are numerous folds and residual colonic materials which mimic the polyps and thus result into FPs. The CAD schemes should have the ability to identify the true polyps and eliminate the FPs to prevent the generation of false alarms in the CAD systems. Nearly all the CAD systems for polyp detection apply an initial segmentation on the images to identify the potential polyps. After this identification, a more refined method is used to reduce the number of false positives which could be triggered by the presence of folds in the colonic walls etc.

When evaluating the performance of CAD algorithms, there is always a trade-off between these two measures. Higher the sensitivity of the algorithm is, lower is the probability of missing the polyps but we have a higher number of false alarms. On the other hand, CAD systems with lower sensitivity towards polyp detection have a lower number of false positives but they are not able to identify the polyps of small sizes. This reduces the feasibility of CAD systems for the purpose of population screening as it can miss some of the potential colonic cancer patients. Ideally, the design aim of the CAD systems is to have 100% sensitivity and 100% specificity.

III. METHODS

A considerable amount of work has been done in the automatic detection of polyps. The available methods make use of different features for the analysis of colon walls. An initial segmentation of the video is usually performed to identify suspicious regions, which could potentially contain polyps and this initial segmentation usually yields a large number of false positives. In subsequent layers of the algorithms, specific detailed features of the polyps are used to identify the true positives (TP) which eventually reduces the FPs. Some of those features and their uses by different CAD systems are discussed in this section:

A. Curvature based methods

Curvature is an important quantity from differential geometry [4], which is widely used in computer vision for visualization applications to characterize the shapes of 3d surfaces. This curvature can be represented by either a scalar or by two vectors indicating the directions of curvature at a given point.

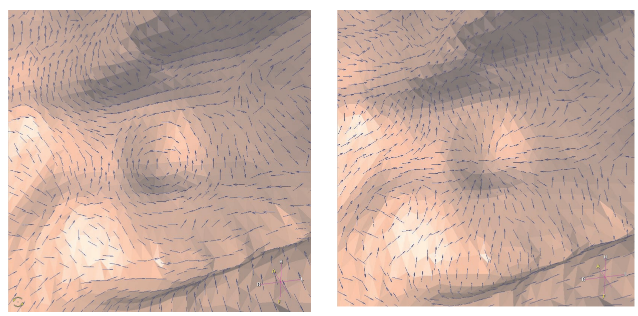

Fig.2. Distinctive patterns on polyp surfaces. Left: Circular pattern in maximum curvature directions. Right: Focusing pattern in minimum pattern directions.

The indicators which are based on scalar curvature have been frequently used in the CAD systems which have been developed for polyp detection. Yoshida [5] used volumetric shape index and curvedness to develop a CAD system. Huang [6] developed a curvature estimation based method on triangular meshes to identify the potential polyps. Van Wijk [7] introduced normalized convolution to measure curvature based features in volume data and used it for automatic polyp detection. Jianhua [8] made use of the fact that the polyp lumen boundaries tend to have convex curvatures and classified the whole colon surface as concave, convex or flat.

The potential of principal curvature has not yet been widely explored, however its direction fields, which can be visualized by the *lines of curvature* have been used for surface shape analysis in engineering design [9]. Lingxaio [10] explored the potential of pattern of streamlines of curvature to develop a CAD system which could identify the suspicious polyps. A visual inspection of the principal curvature directions shows patterns on polyp surfaces that may discriminate the polyps from healthy tissues as shown in the Fig. 2 (taken from [10]).

B. Shape and texture analysis

Several prototypes of CAD systems have been proposed to date which make use of the shape and texture features for identifying colonic polyps with variable success rates. Vining [11] made use of the abnormal colon wall thickness to detect the suspect polyps. Paik [12] made use of the colon surface normals to develop a CAD system which could potentially identify the polyps. Yoshida and Näppi [13] used the shape index to differentiate the polyp from colonic folds and walls. A reduction in the number of FPs is achieved by volumetric features gradient concentration. Based on the assumption that the polyps are composed of spherical objects, Tomasi and Götürk [14] designed a method of fitting a sphere to the isosurface of the voxels on the colon wall. A group of voxels having neighboring spheres are considered as polyp candidates. Kiss [15] used the sphere fitting as a reference to extract some geometric features of the polyp surfaces. Nappi [16] employed morphological dilation to extract suspected polyps. The FPs were further reduced by analyzing the shape features of the suspicious regions.

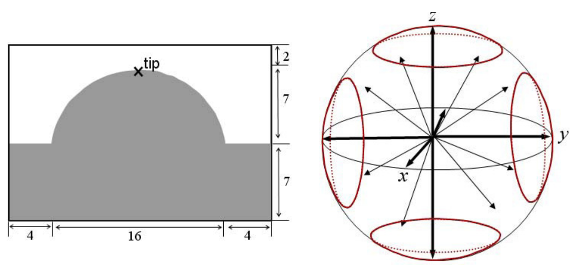

Fig. 3. Shape analysis. Left: A template polyp in 2D. Right: Display the orientation zone of the template, divided into 14 zones.

Yao [8] explored the area of image segmentation using the knowledge guided intensity adjustments. Wei [17] in his work made use of the density and texture information to differentiate between the polyps and healthy tissues. He revealed the internal structure of the polyps using volume rendering with a transfer function called *electronic biopsy.* The difference between the shape features of the polyps and the folds was utilized by Tarik [18]. He exploited the difference in morphology between them to achieve a robust identification and low levels of FPs. Zhouwen [19] used the shape template of the polyps and used sample alignment along some discrete orientation as one of the ways to identify the polyps, the principal of which is shown in Fig. 3 (taken from [19]). All these methods, based on the shape and texture analysis have reported varying levels of performance.

C. Statistical classifiers

Several prototypes of CAD algorithms have been proposed which make use of some statistical classifiers for characterizing the polyp surfaces. In many methods the data, driven by curvature or the visual features of the colon wall are used as an initial indicator of the presence of a potential polyp. They are followed by statistical classifiers to reduce the number of FPs in CAD systems.

Jianhua [8] makes an initial identification of potential lesions and then makes use of the fuzzy clustering, which gives us the probability of one pixel belonging to the polyp regions. David [12] presented a theoretical analysis of *surface normal overlap* by creating simple parametric shape and adding stochastically-governed variations in them to produce realistic anatomic shape models. The model parameters were than compared with the real data-sets to classify the suspect regions. The potential of feature normalized nearest neighbor classifier [20] and probabilistic neural networks classifier was utilized by Tarik [18] for reducing the number of FPs.

Nearly all the CAD methods have implicit classifiers which are usually embedded in the system after an initial characterization of the colon wall into folds and polyps. They are mainly used to refine the search for suspected regions and thus, reducing the number of false positives in a CAD system.

IV. RESULTS

In this section, we discuss the achievements made by the recent methods used for polyp detection when designing a CAD system for colon cancer screening. The success achieved by different methods has varied over time.

Huang [6] achieved a sensitivity of 88.7% for detection of the polyps with a false positive rate of 18.6, which is quite high for this sensitivity compared to the currently available CAD systems. The analysis was performed on dataset which was obtained from 29 patients. Yao [8] was able to achieve 100% sensitivity at a rate of 11.5 FPs per dataset. Amongst the curvature based methods reviewed, Yoshida [5] was able to achieve 100% sensitivity at a FP rate of 2.0 per patient, which is quite low.

Amongst the feature based methods, Götürk [14] was able to achieve a sensitivity of 100% at a FP rate of 28%, Kiss [15] making use of feature based analysis was able to achieve 100% sensitivity for a FP rate of 8.2 per patient whereas Paik [12] achieved the same sensitivity at a FP rate or 6.0 per patient. Tarik [18] obtained a FP rate of 6.0 at a sensitivity of 72.7% and Nappi [16] achieved FP rates of 1.5 with a sensitivity of 100%.

From the results described above, we can observe that we already have very good CAD systems, which can identify the suspicious polyps at a very high sensitivity and specificity but there is still a lot of potential for improvement in classifiers. It is worth mentioning that most of the CAD methods make use of different methods at different layers of the design system in order to reduce the number of false positives. In some cases, the statistical classifiers are implicit in the systems, especially which make use of the shape features. Last but not the least in addition to screening purposes, these CAD systems are likely to take over as major diagnostic systems as a replacement of physician for optimization of time and increase in consistency. Keeping in view these requirements, it is highly desirable to design CAD systems which are robust and at least as efficient as the physicians in identifying cancerous or pre-cancerous lesions in the patients.

V. DISCUSSION

The review of current CAD systems reveals that many attempts have been made to design efficient systems and reduce the number of FPs while keeping the sensitivity higher. Polyp detection is a very hard task as it is difficult to differentiate them from folds and residual material. The evaluation of CAD systems also depends on the quality of the dataset which has been used. This makes the fair comparison of methods a hard task to accomplish. Although considerable success has been achieved in designing CAD systems, and some prototypes of CAD systems are partially functional but there is a dire need to improve the capability of them to envision standalone systems, which can be used for both, training of physicians and robust, efficient and correct diagnosis for the patients.

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