An Online Segmentation Tool for Cervicographic Image Analysis

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ABSTRACT

Cervicography is an important visual screening method for cervical cancer prevention. Automatic segmentation of clinically significant regions in acquired images may provide valuable assistance toward research in cervical cancer detection. This paper presents a Web-accessible cervicographic image segmentation system that incorporates several novel segmentation algorithms developed for particular tissue types and landmarks. The system combines the advantages of two commonly used programming languages, Matlab and Java. It relieves the research groups in academic institutes from the heavy burden of re-developing the sophisticated segmentation algorithms originally implemented in Matlab, while allowing medical experts to evaluate the segmentation algorithms using, perhaps, their own image data acquired at remote locations. It offers attractive properties of flexibility, extensibility and Web-accessibility in a prototype image processing application. The system is integrated with other applications that have been developed for uterine cervix image analysis at the U.S. National Library of Medicine. The architecture and concept of this system are generalizable and can be applied to different medical image processing tasks.

Categories and Subject Descriptors

I.4 [**Image Processing and Computer Vision**]: I.4.0 Image processing software, I.4.6 Segmentation, I.4.9 Applications.

General Terms

Algorithms, Design, Experimentation, Performance

Keywords: Image Segmentation, System Development, Uterine Cervix Images, Cancer Research Tools

1. INTRODUCTION

1.1 Cervicographic Images

Cervicographic images, otherwise called cervigrams, are color photographs of the cervix taken using a specialized camera following the application of a 3-5% acetic acid stain during

cervicography. Cervicography is a low-cost visual technique for cervical cancer screening introduced in the 1970s [1]. It has been used as an alternative or adjunctive method to cytology (Pap smear) for cervical cancer screening in places lacking adequate health care resources. Cervicography incorporates some principles of colposcopy and provides an objective recording of the cervix through photos. The camera used in cervicography is an optical 35mm device with a fixed focus macro lens designed to obtain comparable pictures of cervices across patients, and a mounted ring flash to provide sufficient illumination. The cervigrams, together with the patient's clinical information, are then sent to experienced evaluators for interpretation and assessment. The patient may be referred for further tests, such as colposcopy, if there are any concerns indicated by cervigrams. Cervicography was used in two important cervical cancer studies by the National Cancer Institute - the Guanacaste project [2] and the ALTS project [3]), and over 100,000 cervigram color 35mm slides were collected. These slides were later digitized and archived by the U.S. National Library of Medicine (NLM) for research toward building tools for cancer screening and related work.

1.2 Tools for Cervicographic Image Analysis

Since the importance of images as a knowledge resource in cervical cancer study is widely recognized, we have been developing various software systems to archive, disseminate, retrieve, compress, annotate, and analyze cervigrams. Our goal is to provide practical tools whose development is in synchrony with the research objectives of biomedical collaborators in order to better leverage their expertise in cervical cancer research. To assist in the analysis of cervigrams, segmentation of anatomical structures or pathologically-interesting regions in cervigrams plays a vital role. Our research efforts related to segmentation involve the development of three important tools. They are: Boundary Marking Tool (BMT) [4], Multi-Observer Segmentation Evaluation System (MOSES) [5], and Cervigram Segmentation Tool (CST). The BMT, whose interface is shown in Figure 1, is primarily for data collection. It allows physicians or clinical experts to manually draw boundaries on regions of interest in uterine cervix images and to record detailed diagnostic or descriptive information about the tissue contained within these regions. The development of BMT is sufficiently mature that it has been used in a number of the NCI (National Cancer Institute) studies [6]. The second tool, MOSES, targets the problem of inter-observer variability of region segmentations. It is developed to automatically evaluate the performance of multiple image segmentation approaches. It can also be used to assess the results obtained from an automatic segmentation method by comparing it

to multiple observers' manual segmentations. It has been tested on a dataset of cervigrams in which the cervix and acetowhite lesions were marked by several colposcopist evaluators. The screenshot of the user interface of MOSES is given in Figure 2. The third tool, CST, is the focus of this paper. It provides automatic segmentation of significant tissues in cervigrams and enables medical experts to directly experiment with and evaluate the automatic algorithms incorporated in CST. Together, the BMT, MOSES, and CST comprise a suite of complementary tools which addresses three strongly coupled, recurring tasks in uterine cervix image segmentation: BMT for ground truth collection, MOSES for segmentation evaluation, and CST for automatic segmentation.
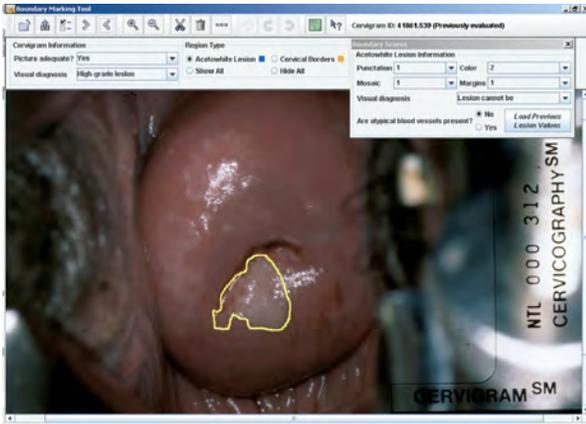

Figure 1. Screenshot of BMT user interface.

Figure 2. Screenshot of MOSES user interface.

In the following sections, we discuss the CST system in detail. Section 2 gives a brief introduction to the automatic segmentation methods developed to extract regions on the cervigrams related to assessment of pathology. Section 3 presents implementation details, such as the framework and the user interface of the system. Section 4 describes the image codec used for cervigram compression and the method for system integration. Section 5 concludes the paper and discusses future work.

2. SEGMENTATION ALGORITHMS

Automatic extraction of key biomarkers in the large Guanacaste and ALTS cervigram collection is a complicated and difficult task, owing to a number of contributing factors, including: 1) the presence in the images of acquisition artifacts such as medical instruments that obstruct the view of important tissues; 2) the large content variability and intensity inhomogeneity presented across the set of images; and 3) the weak boundaries and the close color distributions between tissue regions. We approached this problem by implementing a multi-stage method [7], whose block diagram is shown in Figure 3. It contains the stages of cervix ROI extraction, specular reflection removal, cervix boundary refinement, os detection, columnar epithelium extraction, acetowhite detection, and mosaicism extraction, respectively. Some of the research-level segmentation algorithms have been integrated into the CST system (shown as solid boxes in Figure 3). New algorithms shown as dotted boxes will be integrated as they are developed and evaluated. We briefly describe the algorithms as follows.
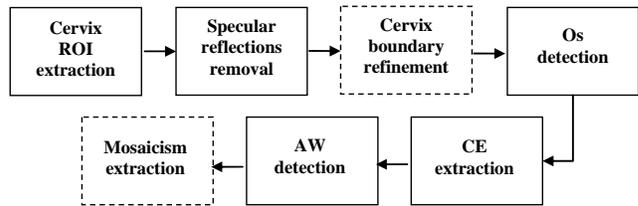

Figure 3. Block diagram of the multi-step segmentation scheme

- Cervix Region of Interest (ROI) extraction

The first step is to extract an approximate boundary of the cervix region to reduce the search space for the subsequent processing tasks (since all biomarkers of interest are inside this region). We used a method proposed in [8] which uses the Gaussian Mixture Modeling clustering technique with the feature set being (1) the *a* channel of the pixel's color in *Lab* color space, and (2) the pixel's distance to the image center. This approach was motivated by the observation that the cervix region has a relatively pink color and is usually located in the central part of the image.

- Specular reflection removal

Specular reflections (SR) are small spots on the cervix surface which have very bright intensity. They are generated by camera flash reflecting from surface fluids. A reliable detection of SR is essential because the close color between regions of SR and acetowhite (AW) could impede the extraction of AW, an important visual feature of cervical neoplasia. To identify SR, a pre-calculated structuring element representing the largest expected SR region was used to apply the morphological top-hat transform to the intensity channel of the color image; the SR regions were then obtained by thresholding the top-hat transformed grayscale image with the threshold found by the Otsu method. To fill the SR regions, each pixel inside the SR region was assigned the mean color of its non-zero neighbors in an iterative process starting from the boundary of the SR region. The details of the algorithms can be found in [9].

- Os detection

The os is the external opening of the uterus that leads into the uterine cavity. It is an important anatomical landmark. The

detection of the os is based on the observation that although its shape, color, size and location vary considerably across the images, the os region is always concave. The detection algorithm consists of three main steps: 1) create an image which represents the concavity of each pixel using a geometric measure of local concavity for the gray-level image surface; 2) identify concave regions which have high-intensity in the obtained image; 3) select the largest region that is close to the cervix center to be the os region. For more details, see the papers [7, 10].

- CE extraction

The columnar epithelium (CE) is one of the major tissue types within the cervix. It usually surrounds the os and appears red with a rough textured surface. Its appearance motivates the use of the following two features for its identification: a texture feature, to represent the coarseness of the tissue, and a color feature, to describe the redness/orange color of the tissue. A multi-scale texture-contrast feature is employed for describing the texture. This feature takes into account both the underlying texture parameters and the texture scale. The *b* channel of the *Lab* color space is used to represent the color characteristics of CE pixels, which contain a characteristic yellow hue. Details on the texture feature and color feature are provided in [7, 10].

- AW segmentation

Among all tissue types, acetowhite (AW) regions are of the most clinical significance, yet represent the most challenging problem, due to large variation in appearance. One of our research efforts to tackle this difficult problem is to exploit a collection of expert annotations that we acquired and used to train Support Vector Machines (SVM) to learn and automatically detect AW regions. The details of this learning-based approach are given in [11]. Details about the effects of using different granularities of the color-based features and different kernel functions of SVM are also compared and discussed in [11].

- Cervix boundary refinement and mosaicism extraction

These two steps are part of our planned future work (see Section 5).

Examples of results of each segmentation algorithm are given in Figure 4. Please note that the results of SR removal, os detection, CE extraction and AW segmentation in Figure 4 are based on the cervix boundary delineated by experts in order to decouple the complexity of finding the cervix boundary from the problem that we are focusing on, which is segmentation *within* the cervix boundary. We have implemented most of these algorithms in Matlab to take advantage of its functionality for numerical computations, matrix manipulations, and image analysis and to quickly develop algorithmic implementations for experimentation.
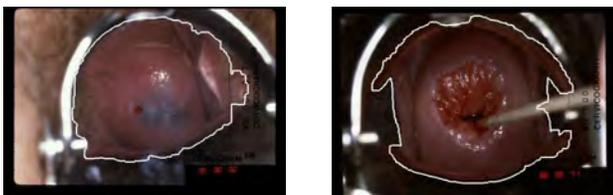
(a) Examples of cervix ROI extraction
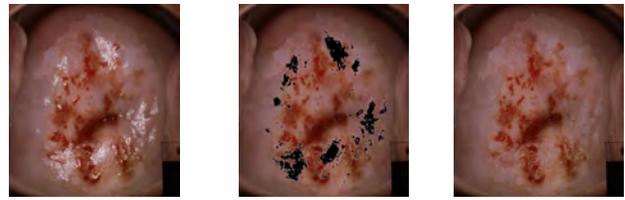
(b) Examples of SR removal
(original image, SR removal, SR filling)

(c) Examples of Os detection (white indicates the os region, red diamond indicates the os center)

(d) Examples of CE extraction

(e) Examples of AW segmentation
Figure 4. Results of cervigram segmentation.

3. SYSTEM DESCRIPTION

There is often a need to let physicians as well as collaborating researchers from different institutions test the algorithms using their own data. This not only allows objective evaluation and comparison of results, but also enables collection of valuable feedback for further improvement. Providing a convenient way to address this need is essential to effective collaboration among computer scientists, engineers, and the medical community, which is very important for the maturity and adoption of medical image processing tools. As previously remarked, for cervigram segmentation, we have implemented most of these algorithms in Matlab. However, there are practical challenges in deploying such prototype systems to multiple geographically distributed sites [12,13]. To execute Matlab programs, either a local installation of the Matlab environment or the operating system-specific software libraries are required along with the developed applications. While open software, such as the Java programming language, may overcome some hurdles, it has a limited set of software libraries available for the highly-specialized mathematical operations we need.

To avoid recoding the segmentation algorithms and to enable Web accessibility to them, we adopted the system architecture shown in Figure 5. It consists of three major components:

- Java client application

The client application developed in Java provides an easy-to-use graphical user interface and collects the end user's input. It also presents the segmentation results and facilitates user interaction. The client application is "pure Java" and can be conveniently deployed to end users from the designated project Web page using Java's Web-start (JWS) technology. JWS also ensures the deployment of the most current version of the tool, which is well suited for our application since the user interface may change frequently as new functionality is added.

- Java servlet

The information collected by the Java client application, including the user-provided image and the types of regions to be extracted, is then sent to the Matlab routines on the server through a servlet. The servlet communicates with the Matlab machine via Java sockets (which are supported by the Matlab Java interface). Since the Matlab Java interface does not support the passing of user-defined structures but only the passing of strings, the servlet also handles the necessary reformatting of the data transferred back and forth.

- Server-side Matlab machine

The server-side Matlab machine runs a specially-written Matlab function, which uses an infinite loop to wait for requests from the servlet and to handle socket calls from the servlet. It accepts the image and other related data forwarded by the servlet and then calls appropriate region/landmark segmentation algorithms to process the cervigram image. It also returns the segmentation results, such as the coordinates of the boundaries of the segmented regions, back to the servlet via the Java socket. The result data is then reformatted and sent back to the Java client for display.
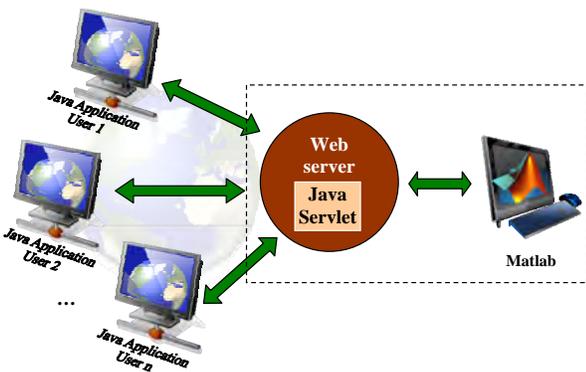

Figure 5. System Architecture of the CST.

By employing such an architecture, the CST proves to be a practical and cost effective solution to the problem facing many research groups who use Matlab to develop algorithms. The user interface of the system is shown in Figure 6. It is simple and clear. Besides the standard menu and toolbar, the interface contains four panels: one for "thumbnail" images, one for image properties, a view panel for the main image display, and a panel for status. Only a few user interactions are required to obtain the segmentation of interest.

4. PRACTICAL ISSUES

Because a major part of the data transferred from the client to the server is the image provided by a user, and the volume of the image

pixel data could be huge, a way to efficiently compress images for fast transmission is necessary. In the field of image compression, a variety of schemes and algorithms have been developed. In our system, we apply the L-BCWT image codec (also called TTC codec) designed and implemented in collaboration with researchers at Texas Tech University [14]. The codec is based on a novel line-based Backward Coding of Wavelet Trees (BCWT) algorithm. It was implemented to follow the Java Image I/O plug-in interface and is able to efficiently encode and decode various types of medical images. First, if the size of the image pixel data is above a threshold, the image is compressed by the TTC codec encoder on the client side; then the compressed image data is sent to the server. In the server, the compressed image is decoded by the TTC codec and then is moved to the Matlab machine to be segmented. Since the TTC compression is lossy, we conducted experiments to analyze the effect of compression on segmentation results. Preliminary tests show that the compression does not degrade the quality of segmentation to a noticeable level. A lossless coding approach achieving similar capabilities is under study and will be investigated and integrated into the CST when it reaches a mature state.
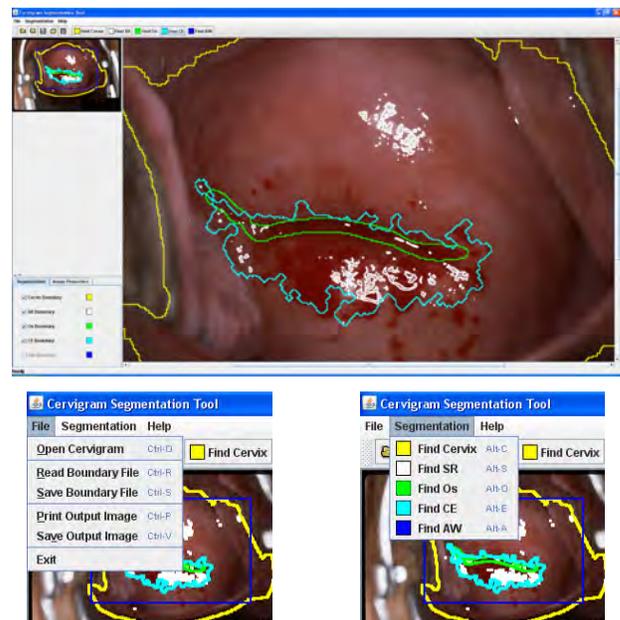

Figure 6. The graphical user interface of CST.

As stated in Section 1, CST is one of the three tools (BMT, MOSES, and CST) developed for analyzing tissue regions in cervigrams. All three tools involve creating or processing region data. We believe that seamless data exchange among these applications has great potential value. For example, it would be very attractive and convenient for users if the region data output by the BMT and the CST could be loaded into MOSES, or the data from BMT could be loaded into the CST, directly without any changes. In addition to data interchange, a uniform data format would also provide benefits for data archiving and data extraction. To this end, the data format in both CST and MOSES are designed to be consistent with that of BMT. The diagram of the XML elements used by CST is shown in Figure 7. Through the use of a consistent data format, BMT, MOSES, and CST are integrated into a unified set or suite of software for cervigram segmentation and analysis.
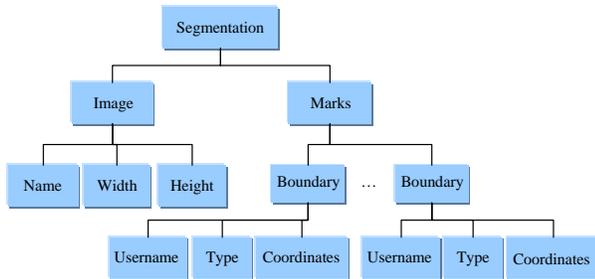
Figure 7. The CST XML elements.

5. CONCLUSION AND FUTURE WORK

In this study, we present an automatic segmentation tool for extracting biomedically-significant regions in uterine cervix images; this tool can be accessed by remote users via the Internet. We have addressed a number of critical practical issues relative to system design and implementation. One distinguishing aspect of our approach is that it combines the strengths of Matlab and Java technology to make Matlab applications available on the Internet. The techniques presented here can be applied to various processing and analysis applications for medical images.

Future improvement of the tool will be twofold: further development of segmentation algorithms and enhancing the tool's functionality. The first includes cervix boundary refinement and acetowhite detection improvement. Since the tissue analysis of interest is conducted within the cervix boundary ("cervix ROI region"), detecting a more precise cervix ROI is crucial for increasing the accuracy and reliability of the whole cervigram analysis system. We have developed an active contour based approach which incorporates prior shape information to refine the initial cervix ROI and obtain a boundary that more closely matches the actual cervix boundary [15] (as marked by experts). We will add this method into the tool after further evaluation. The detection of AW regions is very challenging and still in its early stage. We have obtained initial results for detecting these regions [16]. We plan to add the AW algorithm after further testing and evaluation. Future work on functionality enhancement includes: 1) the addition of functions to allow the user to manually modify and correct the automatic segmentation results, 2) the addition of functions for loading images from the server in addition to loading images from the user's local machine, and 3) functions to allow the detection of subregions within AW that have a "tiled" pattern called *mosaicism*, caused by abnormal vasculature changes, which are of clinical and biomedical research significance.

6. ACKNOWLEDGMENTS

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