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Convenient Semi-Automatic Segmentation Tool

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Abstract: Convenience is one of the most important factors in medical image segmentation. Convenience is defined by compiling opinions from radiologists, and can be described as controllable maximum automation on the condition of producing only accurate results. The components of convenience are inclusive automation and inclusive modification. Inclusive modification consists of verify-and-confirm, undo-redo, exchange of segmentation methods, and intelligent modification tools. Inclusive automation is composed of automatic selection of a method, automatic selection of a confident segment, and automated chores. The convenient segmentation tool has been developed to segment X-ray images for orthopedic surgery, and has received an excellent evaluation from radiologists.

Key words: Convenient segmentation tool, Orthopedic X-ray image, Medical image

INTRODUCTION

Picture Archiving and Communication System (PACS) has come into wide use in general hospitals, which enables a doctor to diagnose a patient by reading CT, MR, ultrasound images at his/her own desk. Diagnosis using visualization and/or quantitative analysis requires segmentation of an interested organ. For instance, the cardiac vessels enhanced by a contrast enhanced medium, need to be segmented for visualization to avoid blocking from ribs, vertebra, and the heart.

The previous segmentation methods can be classified into three categories [1]: region-based methods [2-3], edge-based methods [4-6], and integrated methods [7-9]. Recently, 3D information and medical knowledge have been incorporated to achieve more accurate results [10-13]. The research undertaken so far focuses on how to improve accuracy not convenience, although both of them play important roles in selecting a medical image segmentation tool used routinely at hospitals. Thus, it is necessary to investigate improving convenience.

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This paper defines convenience of medical image segmentation with opinions from radiologists, and defines components of convenience: full control and inclusive automation. Full control means that a user can choose any operation he/she wants when it is necessary. Inclusive automation provides automation in selection of a segmentation method and segmentation results. The paper also describes a convenient segmentation tool designed for the purpose of orthopedic X-ray image segmentation.

METHODS

Definition of Convenient Segmentation Method

Each researcher may have a different definition of convenient segmentation. A radiologist may feel one segmentation tool is more convenient than another one because of his/her taste, and may think a particular aspect as a key factor of convenience. Several tens of radiologists have been interviewed over five years while we have developed commercial and research oriented segmentation tools, which are used routinely in hospitals. Surprisingly, the complied interview data leads to the following consensus opinion on convenience. "The highest possible level of automation is desired only if a segmentation tool can produce accurate results. In addition, the user desires full control over all segmentation operations." Providing controllable automation with accurate results is a key factor for convenience. The reason that a fully automatic method is not accepted as a convenient one is due to a learned experience from the limitations of the current segmentation methods. A golden rule for segmentation is "Any single method cannot provide the best results for all problem domains." Any method may produce unsatisfactory results in some data sets, which requires modification of the results. When modification is difficult to manage, a user feels the method is inconvenient. A user prefers a less automated tool with correct results to a more automated one with incorrect results. Moreover, a user prefers a flexible segmentation tool, in which he/she can change not only the result itself, but also the method to segment.

Full control means inclusive modification, which means not only modifications of results but also modifications of segmentation methods themselves. Inclusive modification consists of four components. Firstly, verify-and-confirm allows a user to verify and confirm the result proposed by a segmentation method. This component saves unnecessary deletions for an unsatisfactory result, which reduces modification time and work. Secondly, undo-redo can recover an action of segmentation. A conventional tool resets whole results, not a specific action. Such reset nullifies whole actions of segmentation, and requires a painful re-segmentation. Thirdly, unrestricted exchange of segmentation methods is supported even in the middle of segmenting if a user wants to select another method. When the current method cannot produce a satisfactory result, another method can be chosen only with a key input. Finally, an intelligent modification tool helps a user to overcome his/her indexterity. For instance, a free draw makes a jagged curve due to jittering of a mouse movement. The jagged curve is transformed into a smooth curve using the intelligent modification tool though the jagged one can be still chosen if a user adhere to it.

Automatic segmentation is conventionally considered to be a method that can produce segmentation results without user intervention. However, the proposed inclusive automation embraces automatic selection of methods, automatic selection of confident segments, and automated chores. Firstly, the most appropriate segmentation method for a target organ is selected automatically. Because a user doesn't have sufficient experience of segmentation or knowledge of image processing, he/she may have difficulties in selecting the best method for a target domain. Secondly, only confident segments from a segmented result are provided to a user as a segmentation result. Fully automated boundary extraction containing 10% of unsatisfactory segments is less convenient than 90% automated boundary extraction containing all satisfactory segments because a user has to modify the unsatisfactory segments. Thirdly, automated chores are functions that can reduce user interaction steps. They are auto-scrolling, boundary closing, boundary/object saving/loading, offline processing, hot-keys, zoom in/out.

INCLUSIVE MODIFICATIAN

Representation of Segmentation Results

For inclusive modification, both segmentation action and its corresponding result should be stored. A segmentation action can produce a segment that can be either a whole boundary of an object or a partial boundary. This segment is the minimum unit produced by a segmentation action. The segment is represented as the CSegment class in C++ terminology, which consists of boundary pixel points, length of the segment, confidence weight for each pixel, etc. An object composed of a group of segments is represented as the CBoundary class, which contains a list of segments, number of segments, active segment identification, etc. An image containing multiple objects is represented as the CBoundaryImage class, which has a list of boundaries, number of boundaries, active boundary identification, row size of an image, column size of an image, etc. These data structures can describe multiple target objects in an image, confidence of a segment, an active segment being delineated or modified. The active segment enables a user to stop segmenting an object without finishing its segmentation, and to start segmenting of another object. Moreover, an object can be revisited for re-segmentation after its segmentation is finished.

Verify-and-confirm

A segmentation action can be defined as a user action to produce a segment. In a conventional seeded region growing method, providing a seed can be a segmentation action. Thus, a user cannot expect the quality of the result produced by the action. If the result is not satisfactory, it should be deleted with an extra action. This procedure can cause not only extra action of deleting but also dissatisfaction with the segmentation tool itself. To overcome such inconvenience, we propose a verify-and-confirm approach. The approach consists of three atomic actions in a segmentation action: a segmentation attempt by a user, providing a tentative result, and verification by the user. Only a satisfactory result is confirmed as a segmentation result. An unconfirmed result is automatically discarded without any further action by a user. This approach is very useful for a segmentation method whose result depends upon an initial user input selection. A user can search and find the best result without experiencing annoying deleting.

The verify-and-confirm mode is initiated when the left mouse button is pressed, and lasts until the left button is released. A tentative result is produced with the current mouse position as an input for a segmentation method. The result is confirmed by keying 'c'.

Undo-redo

A segmentation action is necessary to undo and redo. For this, the segmentation tool stores the following three kinds of actions: adding a segment, deleting a segment, and modifying a segment. These actions are stored using the CUndo class, which contains category of an action, segment information corresponding to the action, and sequence of actions. The undo-redo function allows a user to restore a mistake or to reverse unsatisfactory actions.

Segmentation Methods Exchange

When a user wants to change the current segmentation method into another method in a conventional segmentation tool, he/she has to suspend segmenting, move the mouse for selection of another method, and resume segmenting. This discontinuity of segmenting can be avoided with ranking segmentation methods.

The rank of a segmentation method is determined by the level of automation. If a method is fully manual, it is ranked the lowest. A fully automatic method is ranked the highest. Another concern is similarity of methods. For example, a linear interpolation method can be ranked one level lower than a spline interpolation method. Once all segmentation methods are ranked, exchange of the segmentation method is simply accomplished by keying 'up-arrow' or 'down-arrow' without moving the mouse.

Intelligent Modification Tools

Drawing tools contain line drawing, curve drawing, free drawing, erasing part of a segment, and deleting a whole segment. Intelligent free drawing provides automatic modification of jittering error due to limitations of dexterity. A jagged curve is smoothed with a spline interpolation although the original jagged curve can be still selected if a user wants to.

INCLUSIVE AUTOMATION

Evaluation of a Segmentation Result

Evaluation of a result is conventionally performed by comparing the result with the reference result. However, the reference result is unavailable for an image used in routine diagnosis because the user has to segment the image at the beginning. Instead of using a reference result, most segmentation methods attempt to minimize/maximize their goal functions such as an energy function of a deformable model method. These goal functions may produce good results for some data and bad results for other data, which makes them difficult to apply for evaluation. Moreover, computation of a goal function may take a long time, which is unsuitable for real time segmentation. To overcome such limitations, we propose an evaluation method using a pseudo-reference result.

A pseudo-reference result is composed of only confident segments. A segmentation method generates a result consisting of confident segments and unconfident segments. Because the unconfident segments are inferred by domain specific assumptions such as smooth curvature and continuity, their confidence values may vary severely depending on image characteristics. Thus, only the confident segments are used as a pseudo-reference result. We propose using Canny edges as a pseudo-reference result.

The Canny edges are detected in almost all confident segments in most medical images.

The evaluation function computes normalized deviation from a pseudo-reference result. For all boundary pixels extracted from a segmentation method, the closest distance to a Canny edge is computed. The average of the closest distances is an evaluation value for the segmentation method. This evaluation method with a pseudo-reference result shows a promising result, but still leaves many improvements in the evaluation function itself.

Automatic Selection of a Method

To select the best segmentation method, competing methods should produce results to compare. Because the production of a result requires computing time, the number of competing methods should be small enough to perform real time segmentation. For this, we propose using the ranks of the segmentation method. The rank is described in the section of methods exchange in the inclusive modification. Only the methods with similar ranks are selected for competition.

Initially, the most automatic method is selected as a reference method, and competes with similar ranked methods. Among the competing methods, a method with the highest evaluation value is selected as a reference method. The selected method is then used as a reference method for the next segmentation, and this selection processing is maintained until the segmentation is finished.

The selected result is provided as a tentative result. It can be either confirmed by a user or discarded. In case of the discard, a user can request another tentative result which is produced by a similar ranked method as described in the section of the methods exchange in the inclusive modification.

Automatic Selection of Segments

Most segmentation methods try to extract a boundary as longest as possible. For example, a method designed to extract the whole boundary of an object has to provide whole boundary segments including not only confident segments but also unconfident segments. The unconfident segments can have a low probability of satisfaction from a user, which makes the method inconvenient because the unsatisfied segments need to be deleted and re-segmented. Thus, we propose an approach that provides only confident segments and in which the omitted boundary is left for a user to segment with other methods.

The confidence is computed with the evaluation function described above in the evaluation of a segment result section. The computation is performed at each window, where a window is composed of boundary pixels of length w. The next window is made after sliding w/2 pixels. Only high confident segments are provided. However, the low confidence segments can be still given if a user asks.

AUTOMATED CHORES

Auto-scrolling

For a conventional segmentation tool, a user has to scroll down the window if a target area is cropped because of the limited viewing size. The scrolling requires suspension of segmentation, scrolling by a mouse, and resuming of segmentation. To remove these steps, we propose an auto-scrolling function. If a mouse moves on the fringes of a window at segmenting mode, scrolling is automatically performed so that a window can show a target area for segmentation. This auto-scrolling enables seamless segmentation.

Boundary Closing

An object can be composed of more than one segment, and may have gaps between segments. Because the gaps are usually small, they are difficult to be bridged by manual editing. Such gaps are automatically bridged in the proposed segmentation tool. For each segment, the closest segment is found. If the distance between two segments is less than a threshold, they are bridged. This bridging can be also undone if a user wants to.

Boundary/Object Saving/Loading

Boundary of objects can be stored. The stored boundary can be also loaded. The stored boundary is represented by object-oriented items similar to the DICOM format. Each item consists of a tag, length, and data. Information on a segment is saved with several items such as boundary identification, segment identification, population, boundary pixels, etc. The object-oriented representation provides portability and flexibility of saved data. A data saved by a different version of a data saving format can be still loaded with the newest version of a data saving format because all data is saved with atomic items. The difference in saving data formats is the constituent atomic items, not the atomic items themselves.

Offline-processing

Preprocessing is performed to improve speed of segmentation so that a computation intense method can be done in real time. This preprocessed data is stored in a temporary file, and is loaded when segmentation is started.

Hot-keys

A conventional segmentation tool has to select a function using a mouse, which forces a user to stop segmenting. The proposed convenient segmentation tool allows a user to select all functions with hot-keys so that segmenting is not interrupted by selecting a function.

Zoom In/Out

In addition to zoom in/out with predefined ratios, an image can be scaled by adjusting the size of a window. The initial scale is fixed as 1. When the size of an image is small, a window is automatically sized to fit at the beginning. When the size of an image is too large to fit into a monitor, a part of the image is shown in the maximized window.

RESULTS

The developed convenient segmentation tool starts to segment by clicking 'the convenient segmentation toolbar', and performs segmentation by only moving/clicking a mouse and keying a keyboard. Thus, segmenting is not interrupted to select anything that a user wants. The proposed tool has been implemented for segmentation of X-ray images used in computer aided orthopedic leg surgery. The computer aided surgery has been jointly developed by orthopedics in West Penn Hospital and school of computer science in Carnegie Mellon University. A bent bone is straightened by surgery. Because the surgery is painful and takes several months to recover, correct surgery is a critical issue and can prevent the second surgery. For this, surgery planning has been performed. In the planning stage, a bone should be segmented in an X-ray image. Figure 1a shows an X-ray image whose size is 2048 x 2500. The image loaded on the developed segmentation tool is shown in Figure 1b. Three pins in the leg are screwed for surgery.

When an image is loaded, a temporary file for off-line processing is simultaneously loaded. If there is no temporary file, it is computed once for all. A segmented curve file is also loaded if it exists. The curve file allows a user to resume unfinished segmentation.

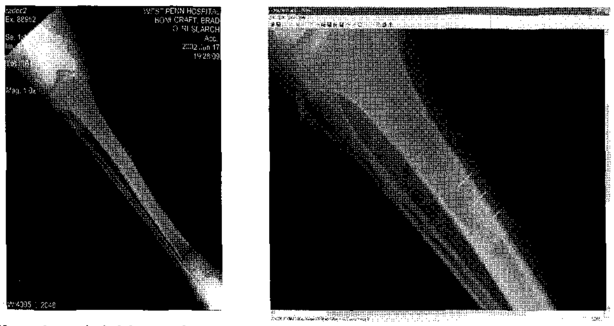

Fig. 1. (a) X-ray Image (b) Segmentation tool

The segmentation mode starts by pressing the 'convenient segmentation toolbar'. When a user moves the mouse while pressing the left button, a segment is extracted if the mouse approaches the boundary of a leg bone. The segment can be confirmed by keying 'c' if it is satisfactory. Otherwise, it is discarded. Another segment can be obtained by moving the mouse while pressing a left button.

The current method may not produce a satisfactory segment, and can be changed into a method with a lower rank so that a segment can be extracted with a more manually controllable method. For example, a method of interpolating user given control points can be changed into a free draw method. The exchange of the methods is simply performed by clicking 'up-arrow' or 'down-arrow' keys.

A boundary is extracted conveniently with inclusive modification functions and inclusive control functions. For instance, segmentation actions can be undone or redone. Moreover, a part of a segment can be erased by moving the mouse while pressing the right button. Finally, segments are bridged into a single object, and stored.

Figure 2 illustrates segmentation results of Figure 1. As shown in Figure 1, medial malleolus in the lower part of the Tibia is overlapped and blocked by a Fibula. This area has been extracted by a method of a more manually controllable method. Moreover pins are also cut to extract only a bone, which gives another reason for using a semi-automatic segmentation method. For twenty X-ray images, segmentation results are achieved within tens of seconds for all users involved in evaluation. The radiologists involved in the segmentation have evaluated the segmentation tool as a very convenient one. To develop a more convenient segmentation tool, evaluation of convenience should be investigated as evaluation of accuracy has been investigated in the research field.

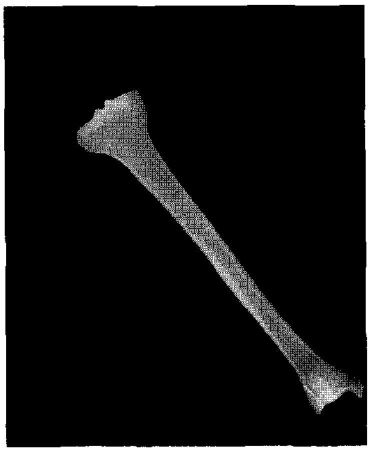

Fig. 2. Result

CONCLUSION

Convenience, one of the decisive factors in selecting a segmentation tool, is defined with inclusive control and inclusive automation, which provides controllable maximum automation on the condition of producing only accurate results. Inclusive control has been implemented with inclusive modification composed of verify-and-confirm, undo-redo, exchange of segmentation methods, and intelligent modification tools. Inclusive automation consists of automatic selection of a method, automatic selection of a confident segment, and automated chores. The proposed segmentation tool has received an excellent evaluation from radiologists. Future research will focus on evaluation of a method's convenience and interpretation of a user's intention so that the most appropriate segmentation method can be selected automatically.

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