An Efficient 3D Segmentation Method for Spinal Canal Applied to CT Volume Sequence Data

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ABSTRACT

With modern treatment planning techniques, the accurate definition of the target volume as well as the organs at risk is a crucial step for the treatment outcome. One of the key organs that must be protected during the irradiation treatment is the spinal canal. Nowadays, high resolution computed tomography (CT) data are required to perform accurate treatment planning, and there is demand for quick but accurate segmentation tools. In this work, a very simple approach that can accurately extract the spinal canal in three dimensions (3D) from CT images is presented. The user must define only the starting point for the algorithm, and the rest of the process is performed automatically. The core of the method is a boundary-tracing algorithm combined with linear interpolation techniques in the longitudinal (z) direction.

Keywords: Boundary Tracking, Computer-Assisted Tools, Segmentation Techniques, Shape Reconstruction, Spinal Canal

INTRODUCTION

Computer tomography has become an important clinical diagnostic tool in radiography. By using computer graphics and advanced rendering algorithms the information provided by these imaging modalities can be fully exploited. To generate views from different anatomical structures contained in CT data sets or to perform treatment-planning techniques, it is essential (1) to extract the corresponding data from the image and (2) to accurately define the target volumes as well as the organs at risk for the treatment outcome; both methods can be done via segmentation process.

Segmentation is the process that separates an image into its important features (primitives) so that each of them can be addressed separately. Humans can perform this task using complex analysis of shape, intensity, position, texture, and proximity to surrounding structures. To perform a similar procedure automatically using a computer since today has been proved a very difficult task. In other cases where simpler anatomical regions with a very distinguishable shape must be identified an algorithm can perform this task. Image segmentation is currently used into several medical imaging applications that involve diagnosis or treatment.

Among several treatment applications radiation therapy treatment of the cancer is an era where segmentation of anatomical volumes...
is an essential procedure. The physicians and physicists have to deal daily with large amount of data that must be segmented accurately and within a reasonable time frame. Standard radiotherapy techniques as well as the modern 3D treatment planning techniques like intensity-modulated radiotherapy aim to maximize the dose delivered to the target while minimizing the exposure of the dose-sensitive structures to high dose, thus increasing tumor control probability without increasing normal tissue complications (De Neve et al., 1996; Isacsson et al., 1997; Pirzkall et al., 2000). Every calculation of the irradiation field position, orientation and size is done based on the shape and location of the target volume and the surrounding organs at risk. In addition to the geometric parameters that are calculated based on the volumes of interest (VOIs), the calculation of the dose distribution is directly related with the characteristics of the VOIs; key organ like spinal canal must be protected during the irradiation treatment. Traditionally the segmentation process is done manually on a slice-by-slice base. Nowadays usually high-resolution CT data are used (60 to 120 slices). Therefore the overall manual segmentation process could last several minutes. In this work we will present an effective semi-automatic method, based on the boundary tracking technique (Haralick & Shapiro, 1985; Gonzalez & Woods, 1992), which improves the time when one or more structures are in use. The implemented algorithms can segment within a few seconds the complete volume of specific organs. The only interaction of the user is to select the starting point in the region of interest and the algorithm will track the object boundaries in 3 dimensions.

**STATISTICAL SHAPE ANALYSIS**

Random fields are stochastic processes whose arguments vary continuously over some subset of $\mathbb{R}^n$-dimensional Euclidean space. They can be strictly defined on a measure space $(\Omega, F, P)$ where $\Omega$ is a set with generic element! $F$ is a $\sigma$ algebra of subsets of $x$, and $P$ is a probability measure on $F$ satisfying the following axioms:

1. $0 < P(A) < 1$ and $P(\Omega) = 1$
2. $P(A \cup B) = P(A) + P(B)$ if $A \cap B = 0$

$A, B \in F$ ; and 0 is the empty set.

**Definition 1:** A second order random field over $S^2 \subset R^3$ is a function $Z : S^2 \to L_2(\Omega, F, P)$

A second order random field has been specified over $S^2$ if a random variable $Z(x)$ has been specified for each $x \in S^2$ with $E\{\|Z(x)\|^2\} < \infty$. We can say that a second order random field over $S$ is a family $Z(x) : x \in S^2$ of square integrable random variables.

A random field $Z(x)$ is wide-sense stationary (or wide-sense homogeneous) if it satisfies the following conditions:

1. $E\{Z(x)\} = m$, where $m$ is constant
2. $E\{(Z(s)-m)(Z(t)-m)^*\}$ is a function of (s-t) only.

A wide-sense stationary random field is called isotropic if

$$R(||s-t||) = E\{(Z(s)-m)(Z(t)-m)^*\}$$

The correlation function of an isotropic random field depends only on the distance between $s$ and $t$. The correlation function of such a random field can be thought as invariant to any rotation around the origin. Let $SO(3)$ denote the group of rotations in $R^3$ around the origin. An isotropic random field can also be defined as satisfying

$$E\{(Z(s)-m)(Z(t)-m)^*\} = E\{(gZ(s)-m)(gZ(t)-m)^*\}$$

where $g \in SO(3)$.

Let $x_1, x_2, \ldots$ be a sequence of points and $x^*$ be a fixed point in $R^3$ for which $|x_k - x^*| \to 0$ as $k \to \infty$. Then if

$$\|Z(x_k) - Z(x^*)\| \to 0$$

as $k \to \infty$.
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