Computers and Electrical Engineering xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Efficient storage of microCT data preserving bone morphometry assessment ☆

Joan Bartrina-Rapesta [a,*], Francesc Aulí-Llinàs [a], Ian Blanes [a], Michael W. Marcellin [b], Victor Sanchez [c], Joan Serra-Sagristà [a]

[a] Department of Information and Communications Engineering, Universitat Autònoma de Barcelona, Bellaterra, Spain
[b] Department of Electrical and Computer Engineering, University of Arizona, Tucson, USA
[c] Department of Computer Science, University of Warwick, Coventry, UK

ARTICLE INFO

Article history:
Received 19 November 2014
Received in revised form 16 June 2015
Accepted 16 June 2015
Available online xxxx

Keywords:
Tomography
Micro-CT
3D morphometry
Medical image compression
DICOM

ABSTRACT

Preclinical micro-computed tomography (microCT) images are of utility for 3D morphological bone evaluation, which is of great interest in cancer detection and treatment development. This work introduces a compression strategy for microCTs that allocates specific substances in different Volumes of Interest (VoIs). The allocation procedure is conducted by the Hounsfield scale. The VoIs are coded independently and then grouped in a single DICOM-compliant file. The proposed method permits the use of different codecs, identifies and transmit data corresponding to a particular substance in the compressed domain without decoding the volume(s), and allows the computation of the 3D morphometry without needing to store or transmit the whole image. The proposed approach reduces the transmitted data in more than 90% when the 3D morphometry evaluation is performed in high density and low density bone. This work can be easily extended to other imaging modalities and applications that work with the Hounsfield scale.

1. Introduction

Human breast, lung, and prostate cancer can induce bone metastasis, which affects the bone structure [1]. To better understand the interactions between these diseases and the bone structure during the development of metastasis, preclinical researchers develop models using small living animals. These models help to evaluate new therapeutic approaches [2,3]. The use of micro-computed tomography (microCT) images has become a common approach to assess structural changes in the bones of animals by means of 3D morphometry [4–6].

During the microCT scanning process, imaging data belonging to air, fat, muscle, bone, bed, and other substances are captured. The reconstruction of the whole volume of the animal has high computational costs due to the large amount of data involved. So, rather than reconstructing and storing the whole volume, in practice, only a relevant volume (RV) that contains a portion of the whole data is reconstructed, stored, and used for the 3D morphometry evaluation.

To obtain qualitative and quantitative bone morphometric measurements, specialists segment the bone tissue from the rest of the data within an RV through a thresholding procedure. This procedure is required because RVs may contain many

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. M.R. Daliri.

* Corresponding author.
E-mail address: joan.bartrina@uab.cat (J. Bartrina-Rapesta).

http://dx.doi.org/10.1016/j.compeleceng.2015.06.020
0045-7906/© 2015 Elsevier Ltd. All rights reserved.

data that do not correspond to the bone tissues. These data are not necessary for the 3D morphometry computation. The 3D morphometry is computed solely using the bone data [6,7]. Research institutions store sets of microCT data in servers to allow their access and distribution to other institutions via the Internet. The Digital Imaging and Communications in Medicine (DICOM) standard [8] is typically adopted to store and distribute such medical images [9]. This standard includes coding (i.e., compression) systems to reduce the size of the data stored. The most relevant coding systems supported in DICOM are Lempel–Ziv–Welch (LZW) [10], JPEG [11], JPEG lossless (JPEG-LS) [12], JPEG2000 [13], and H.264 [14].

Progressive lossy-to-lossless coding of medical images has been widely studied in the literature. Without aiming to be exhaustive, [15] presents a 3D coding technique based on discrete cosine transform and several proposals based on discrete wavelet transform. A modification of the set partition hierarchical trees (SPIHT) method for handling 3D medical data sets is introduced in [16]. An object extension of SPIHT is presented in [17]. Sanchez et al. [18] employed the anatomical symmetries of the human body in a prediction technique that employs the wavelet transform. A JPEG2000 region of interest (ROI) coding method that can prioritize multiple ROIs at different priorities guaranteeing lossy-to-lossless coding for the ROI and the BG is proposed in [19]. More recently, a region-based coding method that distinguishes three different types of regions, namely, ROI, non-ROI, and background is described in [20]. In this work, the ROI is coded with a coding system such as RLE, LZE, or ZIP, the non-ROI is coded with SPIHT, and the background is disregarded. Despite the advantages that these coding systems may provide, none of them is suited for professional medical scenarios. This is because most of them are *not* supported in DICOM, others can only be employed with a particular coding system, some do not recover the original image, and others need to carry out the ROI selection manually.

This paper introduces a novel DICOM-compliant coding strategy that uses the Hounsfield (HU) scale to identify different substances within an RV of a microCT image. These substances are allocated in different Volumes of Interest (VoIs) through a segmentation process performed prior to the data storage. The segmentation process allows the organization of an RV in different VoIs that are encoded independently and then grouped together in a single DICOM-compliant file. Each VoI contains a specific substance. This individual treatment of the substances allows their encoding using any technique included in DICOM. Also, it permits the identification and transmission of the data corresponding to a particular substance with neither decoding nor transmitting the others. This can be conceptually seen as *scalability by substance*, a new feature of the coding system. The proposed method also permits the computation of the 3D morphometry transmitting a reduced amount of data. To enhance the coding performance, an offset operation that compacts the dynamic range of the VoIs is performed. Extended experimental results analyzing coding performance and accuracy of the 3D morphometry validates the soundness of the proposed method.

The rest of this paper is structured as follows. Section 2 briefly describes materials and methods, Section 3 describes the proposed approach, and Section 4 provides results and discussions. The last section concludes this work with a brief summary.

2. Materials and methods

2.1. MicroCT acquisition

The intensity values of microCT volumes are given in HU units. This allows the identification of different substances since they are allocated in non-overlapping ranges of intensity. Table 1 provides the HU scale included in the reference guide of the eXplore Locus device employed in this work (see [21]). The HU scale can be finely adjusted by the specialist thanks to a calibration object that is scanned along with the animal. Other CT images (that are not necessarily microCT) also have a HU scale associated, so our method may be employed for other types of CT images.

2.2. MicroCT analysis

In general, the evaluation of bone structural changes produced by bone metastasis is carried out by computing the 3D morphometry using data corresponding to low-density bone (LB) and high-density bone (HB) [4,6,7,22]. Let BV, BS, and TV respectively denote the bone volume, the bone surface, and the tissue volume of an RV. The tissue volume corresponds to fat, water, low bone, and high bone. The statistics employed in 3D morphometry evaluation to analyze the cancellous bone are V_s, S_v, $Tb.Th$, $Tb.N$, and $Tb.Sp$. They respectively represent the bone volume fraction, the density of the bone for a given VoI, the average trabecular thickness, the number of trabeculae, and the average separation between trabeculae. They are obtained via

$$Tb.Th = \frac{2 - 2V_v}{S_v}, \; Tb.N = \frac{2V_v}{S_v}, \; \text{and } Tb.Sp = \frac{S_v}{2}, \tag{1}$$

$$\text{with } V_v = \frac{BV}{TV} \text{ and } S_v = \frac{BS}{BV}, \tag{2}$$

with V_v and S_v being the bone volume ratio and the bone density for a given VoI, respectively. These architectural measures only depend on BV, TV, and BS for a specific VoI. In the case of a lossless encoding and decoding of a VoI, BV and BS are