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Clinical workflow optimization to improve 4DCT reconstruction for Toshiba Aquilion CT scanners

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Abstract

Respiratory motion remains a source of major uncertainties in radiotherapy. Respiratory correlated computed tomography (referred to as 4DCT) serves as one way of reducing breathing artifacts in 3D-CTs and allows the investigation of tumor motion over time. The quality of the 4DCT images depends on the data acquisition scheme, which in turn is dependent on the vendor. Specifically, the only way Toshiba Aquilion LB CT scanners can reconstruct 4DCTs is a cycle-based reconstruction using triggers provided by an external surrogate signal. The accuracy is strongly dependent on the method of trigger generation. Two consecutive triggers are used to define a breathing cycle which is divided into respiratory phases of equal duration. The goal of this study is to identify if there are advantages in the usage of local-amplitude based sorting (LAS) of the respiration motion states, in order to reduce image artifacts and improve 4DCT quality. Furthermore, this study addresses the generation and optimization of a clinical workflow using as surrogate motion monitoring system the Sentinel™ (C-RAD AB, Sweden) optical surface scanner in combination with a Toshiba Aquilion LB CT scanner. For that purpose, a phantom study using 10

Optimierung des klinischen Workflows zur Verbesserung von 4DCT Rekonstruktionen bei Toshiba Aquilion CT Scannern

Zusammenfassung

Atembewegungen stellen eine der größten Unsicherheitsfaktoren bei strahlentherapeutischen Anwendungen dar. Zeitaufgelöste Computertomographie (4DCT) bietet gegenüber konventionellen CT-Scans den Vorteil, Läsionen möglichst artefaktfrei abzubilden und die Tumorbeweglichkeit darzustellen. Beim Toshiba Aquilion LB CT erfolgt die Rekonstruktion des 4DCT phasenbasiert anhand eines externen Surrogatsignals. Die Qualität der Rekonstruktion hängt dabei stark von der Genauigkeit dieser externen Triggersignale ab, die die Länge eines Atemzyklus definieren. Die einzelnen Atemphasen werden dann durch äquidistante Teilung des Atemzyklus generiert. Ziel dieser Studie ist es, Artefakte dieser Methode durch eine lokal amplitudenbasierte Sortierung (LAS) zu vermindern und die Qualität der 4DCTs zu verbessern. Zusätzlich wird eine Verbesserung der Triggerzeitpunkte in Kombination mit dem Laseroberflächenscanner Sentinel™ (C-RAD

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different breathing waveforms and a retrospective patient study using the 4DCT reconstructions of 10 different patients has been conducted. The error in tumor volume has been reduced from 2.9 ± 3.7% to 2.7 ± 2.6% using optimal cycle-based triggers (manipulated CBS) and to 2.7 ± 2.2% using LAS in the phantom study. Moreover, it was possible to decrease the tumor volume variability from 5.0 ± 3.6% using the original cycle-based triggers (original CBS) to 3.5 ± 2.5% using the optimal triggers and to 3.7 ± 2.7% using LAS in the patient data analysis. We therefore propose the usage of the manipulated CBS, also with regard to an accurate and safe clinical workflow.

Keywords: 4DCT, Local amplitude-based sorting, Radiotherapy, Optical laser surface scanner, Respiratory motion monitoring

AB, Schweden) angestrebt. Dazu wurden Untersuchungen an einem Phantom mit 10 verschiedenen Atemkurven sowie eine Studie an 10 Patienten durchgeführt. Der Fehler des Tumorvolumens konnte dabei am Phantom von 2.9 ± 3.7% auf 2.7 ± 2.6% für optimale phasenbasierte Trigger bzw. 2.7 ± 2.2% für LAS reduziert werden. Die Variabilität des Tumorvolumens konnte in der Patientenstudie von 5.0 ± 3.6% auf 3.5 ± 2.5% bzw. 3.7 ± 2.7% vermindert werden. Auf Grund dieser Ergebnisse favorisieren wir mit Bezug auf die hhere klinische Praktikabilität und geringerer Fehlerabhängigkeit einen zyklusbasierten Ansatz mit optimaler Setzung der Triggerpunkte.

Schlüsselworte: 4DCT, Lokal Amplitudenbasierte Sortierung, Radiotherapie, Optischer Laseroberflächenscanner, Atmungsüberwachung

1 Introduction

In radiation therapy considerable uncertainties in treatment planning of thoracic and upper abdominal sites still remain due to respiratory motion [1]. An increase in treatment margins does account for these motions, but increases the dose to normal tissue [2]. Besides challenging correct treatment delivery, motion of anatomical structures also often deteriorates the image quality of computed tomography (CT) in these treatment regions [3], which later on are being used for treatment planning. Four-dimensional computed tomography (4DCT), also referred to as respiratory-correlated computed tomography (RCCT), can be used to reduce breathing induced motion artifacts which can occur in a "static" CT and allows the detailed investigation of tumor movement with regards to time [4,3,5–7]. Concerning the time-resolution, a certain type of surrogate signal is always needed to sort the acquired oversampled CT raw dataset into multiple datasets, so-called 4DCT phases. Respiratory monitoring systems are required to provide accurate surrogate breathing signals in order to acquire any 4DCT. For Toshiba Aquilion CT scanners, these signals need to be provided as cycle based *online* trigger pulses, each indicating a new breathing cycle. A major problem in providing these prospective trigger pulses is that one has to be certain that each trigger represents the same breathing phase, for example the so-called 0% phase at maximum inhalation. Also, if the CT reconstruction algorithm equally divides the phases in between two trigger pulses, errors in reconstruction cannot be neglected as respiratory motion suffers from irregularities [2,8].

The goal of this study was to generate and optimize a clinical workflow using the Sentinel^{TM} (C-RAD AB, Stockholm, Sweden) optical surface scanner as a surrogate motion monitoring system in combination with a Toshiba Aquilion CT scanner. Also, we investigated the variations of image quality in two different image sorting algorithms: Cycle-based sorting (CBS) and local amplitude-based sorting (LAS) based on a phantom study using 10 different breathing waveforms and a patient study using the 4DCT reconstructions of 10 different subjects.

2 Methods and materials

For the phantom evaluation, 4DCT datasets of a Dynamic Thorax Phantom (CIRS Inc., Norfolk, VA, USA), each with a different breathing curve, were acquired using a Toshiba Aquilion 16 Large Bore CT scanner with the AquilionLB Software Ver3.38ER005 (Toshiba Medical Systems Corporation, Otawara, Japan). The motion signal was recorded using the Sentinel^{TM} optical laser-based surface scanner [9]. As the Sentinel^{TM} is recording the breathing signal via laser on a certain, user-defined spot on the patient's surface, the phantom had to be extended using thermoplastic mask material to simulate a patient's upper body visible to the scanner. This thermoplastic mask is attached to the surrogate motion motor of the CIRS phantom and is used to simulate a breathing motion of a phantom thorax. All 4DCTs for the phantom measurements were acquired and reconstructed with following parameters: slice collimation of 16 × 1.0 mm, helical pitch of 1.2, rotation time of 0.5 s, matrix of 512 × 512, tube voltage of 120 kV and tube current of 150 mA. Images were finally reconstructed in 1 mm slices and a pixel size of 1.074 mm. For the phantom study, an acrylonitrile butadiene styrene (ABS) copolymer sculpture (LEGO®, Billund, Denmark) served as a "tumor" in the lung phantom. This special structure has been used because of its distinct edges and multiple spikes and corners. If the CT image quality is to be determined, these structures serve as a valid measure if they are visible in the reconstruction.