A quantitative comparison of the performance of three deformable registration algorithms in radiotherapy

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Abstract

We present an evaluation of various non-rigid registration algorithms for the purpose of compensating interfractional motion of the target volume and organs at risk areas when acquiring CBCT image data prior to irradiation. Three different deformable registration (DR) methods were used: the Demons algorithm implemented in the iPlan Software (BrainLAB AG, Feldkirchen, Germany) and two custom-developed piecewise methods using either a Normalized Correlation or a Mutual Information metric (featurelet$_{NC}$ and featurelet$_{MI}$). These methods were tested on data acquired using a novel purpose-built phantom for deformable registration and clinical CT/CBCT data of prostate and lung cancer patients. The Dice similarity coefficient (DSC) between manually drawn contours and the contours generated by a derived deformation field of the structures in question was compared to the result obtained with rigid registration (RR). For the phantom, the piecewise methods were slightly superior, the featurelet$_{NC}$ for the intramodality and the featurelet$_{MI}$ for the intermodality registrations. For the prostate cases in less than 50% of the images studied the DSC was improved over RR. Deformable registration methods improved the

Ein quantitativer Vergleich dreier Algorithmen für die deformierbare Registrierung in der Strahlentherapie

Zusammenfassung

In vorliegender Arbeit wird eine Evaluierung verschiedener nicht-rigider Registrationsalgorithmen zur Kompensation interfraktioneller Bewegungen des Zielvolumens und von Risikoorganen anhand von vor der Bestrahlung gewonnenen Conebeam-Computertomographien (CBCT) vorgestellt. Drei verschiedene Methoden zur deformierbaren Registrierung (DR) kamen hierbei zur Anwendung: Einerseits wurde der Demons-Algorithmus der iPlan Software (BrainLAB AG, Feldkirchen, Deutschland) verwendet, andererseits kamen zwei Eigenentwicklungen zur stückweise rigiden Registrierung zum Einsatz. Letztere verwendeten entweder eine normierte Korrelationsmetrik (featurelet$_{NC}$) oder eine auf der Mutual Information basierende Bildvergleichsmethode (featurelet$_{MI}$). Diese Verfahren wurden mit einem neuartigen Phantom für die DR- und klinischen CT- bzw. CBCT-Daten von Prostata- und Lungenkarzinompatienten validiert. Die Ergebnisse wurden anhand

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outcome over a rigid registration for lung cases and in the phantom study, but not in a significant way for the prostate study. A significantly superior deformation method could not be identified.

Keywords: Deformable registration, radiotherapy, organ motion

des Dice- Index (Dice Similarity Coefficient – DSC) für manuell eingezeichnete Konturen und durch die DR generierte Konturen der Zielregionen mit dem Ergebnis einer rigiden Registrierung (RR) verglichen. Im Falle des Phantoms zeigten sich die stückweise rigiden Verfahren leicht überlegen, wobei sich featurelet$_{NC}$ bei der intramodalen und featurelet$_{MI}$ bei der intermodalen Registration auszeichneten. Im Fall der Prostata konnte nur in etwa 50 % der Fälle eine Verbesserung des DSC gegenüber der RR festgestellt werden. Es zeigte sich, dass DR-Verfahren das Ergebnis einer rigiden Registrierung im Fall der Lunge und auch in der Phantomstudie verbesserten, was im Fall der Prostata nicht signifikant nachgewiesen werden konnte. Eine eindeutig überlegene Methode zur DR konnte ebenfalls nicht ermittelt werden.

Stichwörter: Deformierbare Registrierung, Radiotherapie, Organbewegung

1 Introduction

Organ motion is a well known challenge in advanced conformal radiotherapy. The development and clinical introduction of radiation delivery units with integrated imaging option has stimulated research for the management and compensation of inter- and intrafractional patient movements, which is the primary goal of image guided adaptive radiotherapy (IGART) [1]. In general, the aim of IGART is a more precise dose delivery to the clinical target volume (CTV) and while at the same time reducing dose to organs at risk (OAR). Kilovoltage cone beam CT (CBCT) systems attached to conventional C-arm based linacs [2] and megavoltage fan beam CT as applied in tomotherapy units [3] represent today's most widely utilized volumetric imaging methods. In such a treatment concept deformable image registration (DR) is inevitable [4–11]. Meanwhile, a number of commercial systems have been introduced to accomplish the task of deformable image registration [12,13] for adaptive planning.

In general, a DR algorithm consists of (i) a rigid registration step, where translations and rotations are carried out for a gross alignment of the volume image data and if necessary also scaling is done and (ii) an algorithm to improve the match of the volume data content by defining a vector field that compensates for non-rigid motion of tissue [14]. Numerous methods were presented to determine such a vector field and systematic overviews can be found in literature [4,10]. However, verification of the suitability of DR algorithms for clinical routine is scarce.

In this paper, we present a competitive validation of various non-rigid registration algorithms using a novel phantom setup and clinical data. In detail, a groupwise rigid registration algorithm [5] with different merit functions (normalized cross correlation and mutual information) was compared to a novel method based on the demons algorithm [8,16] as implemented in the *iPlan* Software (BrainLAB AG, Feldkirchen, Germany). The validation took place using datasets of an especially designed deformable phantom. Intramodality and intermodality examples were studied as well as patients datasets from prostate and lung cancer consisting of planning CT and CBCT datasets acquired during the treatment course.

2 Materials and Methods

2.1 Piecewise deformable registration algorithm

An implementation of the featurelet-based deformable registration method suggested by Söhn et al. [5] was developed using the Insight Segmentation and Registration Toolkit (ITK, Kitware, Inc. New York, USA).

In the first step of the algorithm temporal subvolumes are created in both images. These are the featurelets (or megavoxels) of size A in the moving image – that is, the image that undergoes the spatial transform – and a search-region of size B defined on the reference image. In Fig. 1(a) a representation of the moving image divided in subvolumes of regular size can be seen; this figure was simplified for visualization, since in the algorithm all areas of the volume are covered by featurelets.

The featurelets of the moving image are then rigidly registered to its corresponding search-region on the reference image using a translation transform, a regular steepest gradient descent optimizer and either a Normalized Correlation Metric (NC) or a Mutual Information Metric (MI) to obtain the final displacement vectors of the megavoxels. Fig. 1(b) shows the original position of the featurelets (blue) and the position after the registration process (red).