Automated marker tracking using noisy X-ray images degraded by the treatment beam

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Abstract

This study demonstrates the feasibility of automated marker tracking for the real-time detection of intrafractional target motion using noisy kilovoltage (kV) X-ray images degraded by the megavoltage (MV) treatment beam. The authors previously introduced the in-line imaging geometry, in which the flat-panel detector (FPD) is mounted directly underneath the treatment head of the linear accelerator. They found that the 121 kVp image quality was severely compromised by the 6 MV beam passing through the FPD at the same time. Specific MV-induced artefacts present a considerable challenge for automated marker detection algorithms. For this study, the authors developed a new imaging geometry by re-positioning the FPD and the X-ray tube. This improved the contrast-to-noise-ratio between 40% and 72% at the 1.2 mAs/image exposure setting. The increase in image quality clearly facilitates the quick and stable detection of motion with the aid of a template matching algorithm. The setup was tested with an anthropomorphic lung phantom (including an artificial lung tumour). In the tumour one or three Calypso® beacons were embedded to achieve better contrast during MV radiation. For a single beacon, image acquisition and automated marker detection typically took around 76±6 ms. The success rate was found to be highly dependent on imaging dose and gantry angle. To eliminate possible false detections, the authors implemented a training phase prior

Automatisierte Markererkennung zur Bewegungsnachführung in vom Therapiestrahl stark beeinträchtigten Röntgenbildern

Zusammenfassung

In dieser Studie wird die Detektion von intrafraktioneller Organbewegung unter Verwendung von kV-Röntgenbildern, welche durch den MV-Behandlungsstrahl stark beeinträchtigt sind, mittels automatischer Markererkennung in Echtzeit demonstriert. Die Autoren haben in einer bereits publizierten Studie die In-line-Bildgebungsgeometrie vorgestellt, in welcher der Flat-Panel-Detektor (FPD) direkt unter dem Bestrahlungskopf des Linearbeschleunigers sitzt. Dabei wurde beobachtet, dass die 121-kVp-Röntgenbilder in ihrer Qualität durch die gleichzeitigen Wechselwirkungen des 6-MV-Therapiestrahls mit dem FPD sehr eingeschränkt sind. Die MV-induzierten Bildartefakte stellen eine besondere Herausforderung für automatische Marker-Detektions-Algorithmen dar. Für diese Studie haben die Autoren eine modifizierte Bildgebungsgeometrie entwickelt: dazu wurden der FPD und die Röntgenröhre relativ zum Therapiestrahl verschoben. Dies erhöhte das Kontrast-zu-Rausch-Verhältnis zwischen 40% und 72% bei einem Setting von 1,2 mAs/Bild und ermöglichte eine schnelle und stabile Detektion der Bewegung mittels eines

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to treatment beam irradiation and also introduced speed limits for motion between subsequent images.

Keywords: Real-time tumour tracking, intrafractional motion, X-ray image guidance, fiducial marker, in-line geometry

template-basierten Algorithmus. Der Aufbau wurde mittels eines anthropomorphen Lungenphantoms untersucht. Ein implantierter Lungentumor wurde mit einem oder drei Calypso® Beacons ausgestattet um einen besseren Kontrast während der MV-Bestrahlung zu erhalten. Unter Verwendung eines Beacons dauerte die Bildaufnahme und automatische Markererkennung ca. 76±6 ms. Die Erfolgsrate war stark abhängig von der Bilddosis und dem Gantrywinkel. Um mögliche falsche Markererkennungen zu eliminieren, haben die Autoren eine Trainingsphase vor der MV-Bestrahlung sowie Geschwindigkeitsgrenzen für die Bewegung zwischen aufeinander folgenden Bildern implementiert.

Schlüsselwörter: Tumordetektion in Echtzeit, intrafraktionelle Bewegung, röntgenbildgestützte Nachführung, Referenzmarker, In-line-Bildgebungsgeometrie

1 Introduction

Intrafractional motion management is one of the remaining challenges in image-guided radiotherapy [1]. The traditional strategy to dosimetrically account for motion is to add safety margins around the treatment field [2]. This margin strategy considers the effect of intrafractional motion at the cost of healthy tissue irradiation [3]. Another approach, followed by our group and others [4,5], is to shrink motion related margins as much as possible and dynamically adapt the treatment field to the current position of the tumour. This technique strongly depends on constantly updated, exact knowledge of the internal tumour position. One fast and widely available imaging modality for this purpose is linac-integrated kilovoltage (kV) X-ray imaging. Different intrafractional imaging geometries were utilised in previous studies: e.g. the orthogonal [6], the stereoscopic [7] and the in-line [8] geometry.

The original in-line geometry [9], in which the kV imaging and megavoltage (MV) treatment beam are perfectly aligned (config. I, Fig. 1 (a)), is not suitable for tumour tracking during MV irradiation, because of the overlap of kV and MV field on the flat-panel detector (FPD). Fast et al [8] shifted the X-ray source 13 cm toward the gantry and thus effectively tilted the kV beam by 5.4° to create a geometric separation of MV and kV fields suitable for intrafractional imaging (config. II, Fig. 1 (a)). The system is capable of tracking most target motions perpendicular to the treatment beam, the direction that usually features steep dose gradients. In principle, it is also possible to monitor the shape of the treatment field using this geometry, a feature that could provide useful additional information when the treatment is dynamically adapted. In their approach, however, poor kV image quality and MV-induced artefacts still posed a considerable challenge for automated tumour detection. Major artefacts caused by the treatment beam are an increase of noise through scatter within the detector, the multi-leaf-collimator (MLC) leakage and MV stripe artefacts. The latter artefact is caused by the pulsed nature of the MV beam and the non-synchronous FPD readout [10].

In this study we have enhanced the modified in-line imaging geometry [8] further for better kV image quality and reduced MV-induced artefacts. This was achieved by repositioning the FPD and kV tube with respect to the treatment beam (config. III, Fig. 1 (a)). Importantly, we also rotated the FPD 90° about the treatment beam axis to improve its read-out behaviour. A stripe reduction algorithm was implemented to mitigate the effect of the MV stripes.

The aim of this study was to develop and improve an automated method for real-time detection of respiratory target motion during treatment with the aid of metallic markers based on X-ray images acquired in the new in-line geometry. The real-time requirement is crucial for performing the motion compensation adequately and yielding the required dosimetric effect [11]. The accuracy of the detection algorithm is equally important, and we established a training phase prior to MV irradiation to exclude incorrect marker positions during treatment. To gauge the suitability of the new imaging geometry for target localisation, we experimentally simulated respiratory tumour motion by using an in-house built anthropomorphic lung phantom with implanted Calypso® (Varian Medical Systems, Inc., Palo Alto, CA, USA) beacons as markers. Simple sinusoidal trajectories that simulate regular respiration were complemented by more irregular breathing patterns that mimic the effect of coughing. Following the suggestions by Harris et al [12], we implemented a template matching algorithm based on normalised cross-correlation to automatically detect the marker motion. Previous studies [13–15] have demonstrated that automated marker detection with grey-value templates can yield excellent results when