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Technical notes

Automatic tracking of gold seed markers from CBCT image projections in lung and prostate radiotherapy

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ABSTRACT

Purpose: To construct a method and software to track gold seed implants in prostate and lung patients undergoing radiotherapy using CBCT image projections.
Methods: A mathematical model was developed in the MatLab (Mathworks, Natick, USA) environment which uses a combination of discreet cosine transforms and filtering to enhance several edge detection methods for identifying and tracking gold seed fiducial markers in images obtained from Varian (Varian Medical Systems, Palo Alto, USA) and Elekta (Kungstensgatan, Sweden) CBCT projections.
Results: Organ motion was captured for 16 prostate patients and 1 lung patient.
Conclusion: Image enhancement and edge detection is capable of automatically tracking markers for up to 98% (Varian) and 79% (Elekta) of CBCT projections for prostate and lung markers however inclusion of excessive bony anatomy (LT and RT LAT) inhibit the ability of the model to accurate determine marker location.

Introduction

Treatment outcome in radiotherapy is highly dependent on setup error [1] and organ motion and for treatment sites that are prone to movement organ motion plays a significant role. Prostate cancer, a common cancer found among men in Australia [2], is one such site that is vulnerable to organ motion which is caused by bladder and rectal filling. Another common cancer that is highly prone to movement due to respiration is lung cancer. This motion during treatment is known as intrafraction motion.

Intrafraction motion of tumour volumes can be substantial in prostate [3] and lung [4] radiotherapy. To adequately address tumour motion without image guidance requires increased treatment volumes which may increase dose to healthy organs. To assess tumour motion, and necessary treatment volume, in individual patients requires the use of tumour tracking systems.

Methods to assess tumour motion during a treatment fraction with planar x-ray imaging include using MV and kV stationary beams [5–8], limited MV projections [9], kV arcs [10,11] or MV arcs [12]. Other methods to assess tumour motion during treatment fractions include fluoroscopic tracking [13,14], ultrasound [15], electromagnetic transponders [16] and radioactive markers [17]. Other techniques include images from cone beam CT [18–23] and megavoltage cone beam CT [24]. These authors identified organ motion albeit with differing techniques.

We have developed a methodology and accompanying software platform that employs edge detection algorithms to track gold markers, and hence target motion, through a sequence of CBCT image projections for patients undergoing prostate and lung radiotherapy. CBCT-based tracking was chosen over other devices because it's a common radiotherapy device in Australia and an already established target localiser. The purpose of this study was to produce an instantaneous motion tracking methodology that could make use of existing technology such that intrafraction motion management would be accessible at minimal cost.

Methods

The CBCT images used in this study were acquired from Varian 21iX and Elekta Synergy linear accelerators. The images were copied from the reconstruction PC onto a hard disk. The Varian images were converted from .hnd to .bin files using custom software. Matlab version 8.3.0.532 (2014a) was used for developing the software to read and evaluate the markers.

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Each CBCT projection (image) is generalised into two user-defined categories: prostate or lung. Prostate is the default setting. Lung only serves to lessen the criteria definition of what constitutes a seed (this will be explained later). To separate and grade each image an evaluation of the contrast threshold using Otsu's method[1] is performed.

The criteria used to assess images and limit the number of false positives from edge detection include: outlier tolerance, tracking window size, and seed size. Outlier tolerance determines whether a seed has been located near the most recently detected seed. For lung data this tolerance is larger since the seed location will move with breathing. However, the seed location will also move between projections regardless of breathing as the gantry rotates about an axis that is most likely not at the seed centre. Tracking window size is a cropped window centred on the seed which is defined by the user on the first image. The moving window technique greatly improves seed detection and operation speed. Seed size is in pixels and is a dependent of all other criteria. These criteria increase the probability of locating and tracking the seed between images.

Once image processing is initiated the user selects the starting location of the seed in the first image. The program processes the image based on its contrast before attempting to locate the seed(s). If the seed is located near the starting location selected by the user then the position is recorded and the next image processed with the new position.

Image enhancement is performed by two edge detection algorithms; Prewitt[2] and Roberts[3] approximations. The two detection methods form the basis for defining each seed location. However, prior to seed detection each image is processed to improve the contrast between seed and surrounding anatomy. For images with low to no detectable contrast multiple edge detection processing is performed. Some images are passed through different filters to reduce the number of structures detected. For image enhancement to be optimised the images are divided into three regions based on their contrast rating: poor, moderate and good. Processing the images in this way serves to better define the contrast between seed and surrounding anatomy.

Images are grouped into two categories: prostate or lung before separating between Elekta or Varian. The different venders use opposite ends of the greyscale so further categorising is necessary. In addition, the amount of patient scatter also degrades the image contrast so this adds more categories. Thus, image processing is dependent on the treatment site (prostate or lung), the vender (Elekta or Varian) and the image contrast (poor, moderate, or good). Contrast enhancement for each of the poor, moderate and good rated contrast categories is described below.

To test the image processing package a Sun Nuclear Corporation (Florida, USA) MotionSim treatment simulator was utilised. Static and sinusoid breathing patterns were simulated on the platform using a CIRS (Virginia, USA) phantom and the images analysed.

Contrast rating poor

Images with Otsu's threshold value ≥ 0 and <0.0005 for Varian and values $= 0$ for Elekta constitute poor image quality.

Varian images

Images in this region have their values clipped to a minimum value plus 15. This lessens the magnitude between minimum and maximum values; any high contrasting structures are clipped. The 135° response to the Roberts approximation is then determined before twice passing a medium filter over the data. This removes single or multiple entity pixel structures surrounding larger areas of contrast. The resulting image is passed again through the Roberts operator to find the contrasting edge. Finally the structures that remain are morphed[4] to recreate any data lost during filtering. The process removes many small contrasting structures but can also dismember seed-like structures therefore morphing is required to reform the seed once again. Morphing is performed using several varying sized disk-shaped structures.

Elekta images

Images in this region are transformed using the discreet cosine transform[5] (DCT) and the signum[6] constructed. The Prewitt approximation is then created from the sign of the inverse DCT and the remaining structures morphed similarly to the method for Varian low contrast images.

Contrast rating moderate

For either Varian (threshold >0.0005 and <0.005) or Elekta images (threshold >0.985) with moderate contrast a Prewitt edge detection is used and the resulting image filtered by an unsharp[7] filter.

Contrast rating good

Any images where the contrast is deemed good; the DCT and signum function are again used but with the Roberts approximation. With respect to threshold, images were deemed good for Varian images having a threshold >0.005 and for Elekta image thresholds >0 and <0.985.

Results

Figure 1a–d shows the low contrast image progression and Fig. 1e and f shows the moderate contrast image progression which is similar to the images assessed as good. Notice the differences between the small contrasting shapes on the left of image (Fig. 1c) and how they are reduced or eliminated in Fig. 1d. The final image is a binary of the original image accentuating the location of each seed.

Seeds implanted in the MotionSim phantom for a static and sinusoid breathing pattern is shown in Fig. 2. Notice the elliptical motion of Fig. 2c and d which occurs as a product of the gantry rotation and the offset between the axis of rotation and the seed. If there is no motion then this should be a complete sinusoid with amplitude two times the offset. Also note the discreet bands of data in Fig. 2a, since we know this seed is stationary then the changes observed here is a result from either or a combination of rounding errors in the seed location, gantry shifts (bearing clearance), tube or imaging panel shifts and incorrect assessment of the seed's location.

Figure 3 shows the tracking results for one seed, inserted into the prostate, as it appears through a set of Varian CBCT image projections. Notice the spread of data at the start, in the centre, and

[1] Otsu's method (http://en.wikipedia.org/wiki/Otsu%27s_method).
[2] Prewitt operator (http://en.wikipedia.org/wiki/Prewitt_operator).
[3] Robert approximation (http://en.wikipedia.org/wiki/Roberts_cross).
[4] Morphing (http://www.mathworks.com.au/help/images/ref/imclose.html).
[5] DCT (http://en.wikipedia.org/wiki/Discrete_cosine_transform).
[6] Signum (http://en.wikipedia.org/wiki/Signum_function).
[7] Unsharp masking (http://www.mathworks.com.au/help/images/ref/fspecial.html).