Respiratory Motion Estimation Using Visual Coded Markers for Radiotherapy

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ABSTRACT

Respiratory motion is an important issue in radiotherapy as it can cause many problems such as damages to healthy tissues. Different methods have been introduced to estimate the respiratory motion but most of them need some electronic devices or expensive materials. In this research, we proposed a respiratory motion estimation method by tracking inexpensive and easy to use visual coded markers using stereo vision.

Categories and Subject Descriptors

I.4 [**Image Processing & Computer Vision**]: Motion Estimation

General Terms

Algorithms, Measurement, Design, Experimentation

Keywords

Radiotherapy, Respiratory Motion, Marker Tracking

1. INTRODUCTION

Radiotherapy is widely used technique, generally as a part of cancer treatment to control or kill malignant cells. Intrafraction motion caused by respiratory, skeletal muscular, cardiac, and gastrointestinal systems is an important issue in the era of image-guided radiotherapy [2]. Among these intrafraction motions respiratory motion got lot of research attentions as it induces significant internal movements and causes many problems like image acquisition limitations, treatment planning limitations and radiation delivery limitations.

If respiratory motion not accounted correctly, motion artifacts can be resulted in CT images and affected to target/normal tissue delineation and dose calculation accuracy. In treatment planning adding margins to cover the limits of the motion may increase the radiation field size and consequently the volume of healthy tissues exposed to high doses. In the other hand if the margins are not large enough, part of the clinical target volume will not receive advocate dose coverage. In the phase of radiation delivery, presence of respiratory motion causes an averaging or blurring of the static dose distribution over the path of the motion.

As a solution to these problems many different methods to handle the respiratory motion such as motion encompassing, respiratory gating, breath holding, forced shallow breathing with abdominal compression and real-time tracking have been introduced. In breath-holding techniques patient is asked to hold the respiration for short intervals and deliver treatments during these intervals. However, this technique is especially difficult for patients having compromised pulmonary function which is the case for most of the lung cancer patients. Forced shallow breathing techniques use a physical plate over the abdominal region to restrict the breathing motion but it cause great patient discomfort. Respiratory gating techniques use an external marker to calculate the respiratory cycle and periodically turn on the treatment beam when the breathing parameters fall within a predefined range [3]. These breath-holding and gating technique have extra burden such as handling patient movements, longer treatment time, patient training and model instability.

Real-time target tracking techniques have been proposed to solve these problems by actively estimating the motion and tracking the target. The Calypso: prostate motion tracking system integrated in Varian (Varian Medical Systems, Palo Alto, CA) implant three tiny transponders shows in Figure 1-c into the prostate to send tracking signals to the system [5]. When the prostate moves outside the planned treatment area, the radiation beam can be stopped to minimize the damage to healthy tissues. The BrainLAB ExacTrac positioning system use implanted fiducial markers with external infrared reflecting markers (Figure 1-b) to align the patient and gate the treatment beam [1]. The Synchrony respiratory tracking system, a subsystem of CyberKnife is

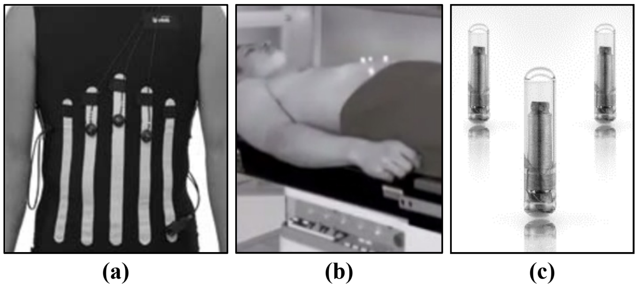
(a) (b) (c)

Figure 1: Various types of motion tracking systems used in radiotherapy.

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the first technology to continuously synchronize beam delivery to the motion of the tumor tracked using a fiber optics marker vest (Figure 1-a) [4].

In this research we experiment the feasibility of using cost effective and easy to handle visual coded markers (AR markers) to detect the respiratory motion instead of using electronically connected complicated markers which are used in previous works. Another advantage of using visual markers over IR markers is the ability to estimate the orientation of a single marker without using neighboring information.

2. SYSTEM OVERVIEW

Visual coded markers are design so that they are small enough to attach to the affected area of human body. A calibrated stereo camera is used to capture the images of attached markers and image processing algorithms are used to track the markers in real-time. 3D coordinates of each marker can be calculated using the exact 2D coordinates of the marker in left and right images. Then these 3D information is used to estimate the motion of attached surface. Figure 2 shows an overview of the proposed system.

2.1 Marker Encoding

Markers, which are used in the proposed system, are designed as a 3×3 window bordered with a thick black color boundary. Random assignment is used to encode the binary code-word to the 3×3 window and at least one symbol should be connected to the border to avoid two near square contours. Uniqueness and rotation invariant constraints are considered to avoid ambiguities.

2.2 Marker Detection and Decoding

Marker detection process starts with binarization of both left and right captured images using adaptive thresholding technique which is very robust to image noise, contrast and other variations. Adaptive thresholding defines different threshold values for each pixel in the image by examine the surrounding neighborhood pixels. After thresholding the images, a contour detection algorithm with several refinement steps is applied to detect possible markers on the image. Contour size and polygon approximation are used as refinement stages to separate square contours, which can possibly be the markers, from other contours. Using four corner information of square contours, perspective transformation is calculated to find the orthogonal (top) view of the marker. Then the marker ID can be identified by applying a 3×3 window mask to the top view of the markers.

When the marker IDs and their coordinate information are known in both views, 3D coordinates of each marker can be calculated using the calibration parameters and triangulation techniques as shown in Figure 3.

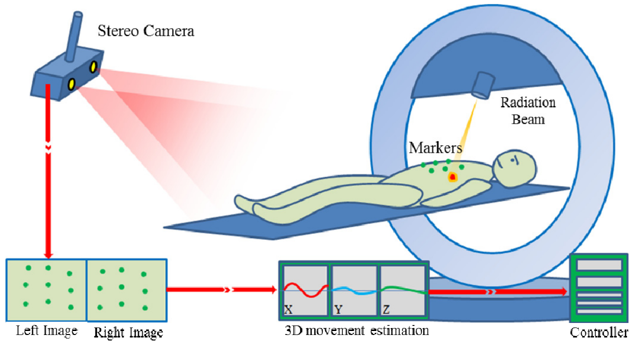
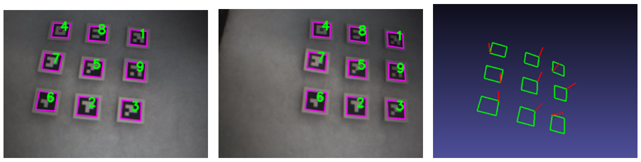


Figure 2: Overview of the proposed system.



(a) Left Camera (b) Right Camera (c) 3D Information

Figure 3: Marker detection results of the both views and calculated 3D information.

2.3 Motion Estimation

We can calculate displacement, acceleration, and rotation information of each marker independently using the 3D coordinate which are acquired in the previous stage. Displacement of a marker M at time t can be defined by Equation (1), where $m_t(x, y, z)$ is the 3D location of the marker. Acceleration A of a marker M at given time t can be calculated by Equation (2) using displacement information. If we have found the centroid (c_t) of the marker using four corner information m_t^i, rotation R can be found using SVD as shown in Equation (3) & (4).

$$D_t(M) = m_t(x, y, z) - m_{t0}(x, y, z) \qquad (1)$$

$$A_t(M) = (D_{t-2}(M) - 2D_{t-1}(M) + D_t(M))/\Delta t^2 \qquad (2)$$

$$H = \sum_{i=1}^{4} (m_t^i - c_t)(m_{t0}^i - c_{t0}) \qquad (3)$$

$$[U, S, V] = SVD(H), \quad R_t(M) = VU^T \qquad (4)$$

3. DISCUSSION

In this paper we proposed a respiratory motion estimation system using visual coded marker tracking technique. We tested the system with different experiments and able to maintain high marker detection rate with real-time performance. Accuracy of the motion estimation is evaluated by connecting a visual marker to an IMU sensor and estimation the motion using both marker and sensor. During the experiment we found some inconsistencies of the 3D information due to the lack of robustness in decoding stage. Currently we are planning to enhance marker encoding and decoding phase to remove these inconsistencies and enhance the accuracy.

4. ACKNOWLEDGMENTS

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