# Incorporating electromagnetic tracking into respiratory correlated imaging for high precision radiation therapy.

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## Abstract

It is well established that respiratory motion has significant effects on lung tumor position, and incorporation of this uncertainty increases the normal lung tissue irradiated. Respiratory correlated CT, which provides three dimensional image sets for different phases of the breathing cycle, is increasingly being used for radiation therapy planning. Cone beam CT is being used to obtain cross sectional imaging at the time of therapy for accurate patient set-up. However, it is not possible to obtain cross sectional respiratory correlated imaging throughout the course of radiation, leaving residual uncertainties. Recently, implantable passive transponders (Calypso® Medical Technologies) have been developed which are currently FDA-cleared for prostate use only and can be tracked via an external electromagnetic array in real-time, without the use of ionizing radiation. A visualization system needs to be developed to quickly and efficiently utilize both the dynamic real-time point measurements with the previously acquired volumetric data. We have created such a visualization system by incorporating the respiratory correlated imaging and the individual transponder locations into the Image Guided Surgery Toolkit (IGSTK.org). The tool already allows quick, qualitative verification of the differences between the measured transponder position and the imaged position at planning and will support quantitative measurements displaying uncertainty in positioning.

**Keywords:** Localization & Tracking Technologies, Multi-Modality Display, Registration, Visualization

## 1 Introduction

For radiation therapy of tumors within the thoracic cavity, respiratory motion can account for substantial displacements. There are a variety of techniques aimed at modifying dose delivery to account for respiratory motion (e.g. respiratory gating, DMLC tracking)[1]. In addition, a variety of imaging techniques are used to reduce respiratory related motion artifacts. One such technique, 4DCT imaging, relies on the common modality of CT imaging; however it couples an external surrogate to record respiration.

### 1.1 4DCT Acquisition

The basis for 4DCT imaging is that if enough images are acquired for each slice position, one of those images will correlate to a given phase of the breathing cycle. For a ciné mode CT scanner, the 4DCT acquisition procedure in our research group is as follows.[2] First, the patient is placed on the couch and a spirometer is placed in the mouth and a pneumatic bellows is placed around the abdomen (to compensate for spirometry drift). Both external breathing surrogate signals are fed into a computer, along with the x-ray on signal that synchronizes the CT image acquisition with the respiratory signal. For each axial slice, numerous (~25) images are acquired of the same spatial location. This process is repeated for the entire volume to be imaged. After acquisition, the data is post-processed. Different phases of the breathing cycle (i.e. mid inhalation, max exhalation) can be reconstructed from the oversampled data. There are a variety of algorithms that correlate the external surrogate breathing waveform and determine which slice most accurately represents a given phase. At Washington University, a percentiles algorithm called WashU View is used.[3] For instance, to reconstruct at a 90% (peak inhalation), the algorithm selects an image that was acquired at a time in the breathing waveform that is larger than 90% of the acquired signal. This is analogous to sorting all of the amplitudes acquired from the external surrogate, then setting a benchmark at 90% of the length of the array. This value will be used for reconstructing maximum inhalation. For a given slice from the CT scanner, the image that is closest in amplitude to this benchmark is selected. This process is repeated for all slices along the volume until a 3D CT image is reconstructed for a given phase. This can then be repeated for multiple phases of the breathing cycle to generate a series of 3D volumetric datasets.

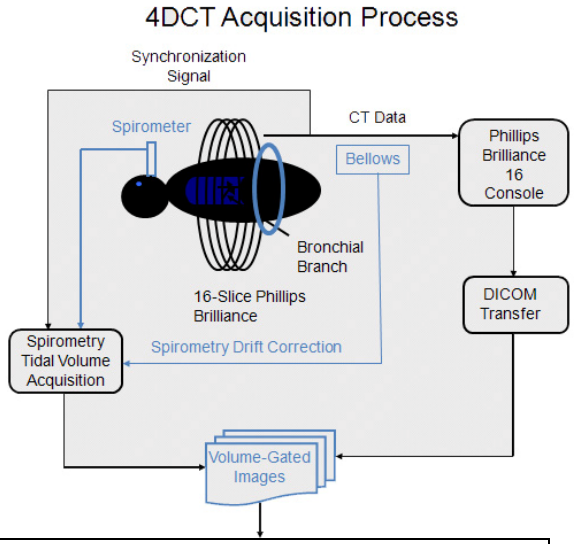


Figure 1: 4DCT Acquisition Process. Respiratory information along with a CT synchronization signal is recorded via computer interface. Reconstruction is later performed in order to obtain 3D volumetric image sets corresponding with different phases of breathing

## 1.2 Tracking

Most forms of linear accelerator motion management use linear accelerator gating based on an external surrogate. Some examples of external surrogates are the pneumatics bellows placed around the abdomen as described in the 4DCT section, the use of an optically tracked block on the patient abdomen as used in the Varian RPM (Varian Medical Systems, Palo Alto, Ca) implementation, and the use of infrared light and stereoscopic cameras to 3D model the exterior of the patient as employed with the GateRT surface imaging system (VisionRT Ltd, London, England). These techniques are non-invasive and inexpensive; however it has been found that internal tumor motion does not always correlate with the motion of external anatomy.[4] This has led many to try and track discrete points within the thoracic cavity. The only real-time method of tracking intrathoracic tumors has been the use of fluoroscopy or intermittent kV imaging. This is most often accomplished with the implantation of gold fiducials into lung tumors.[5,6] The custom hardware installations and extra imaging dose precludes use of these techniques for conventionally fractionated radiation therapy. We are investigating a technique that uses implanted

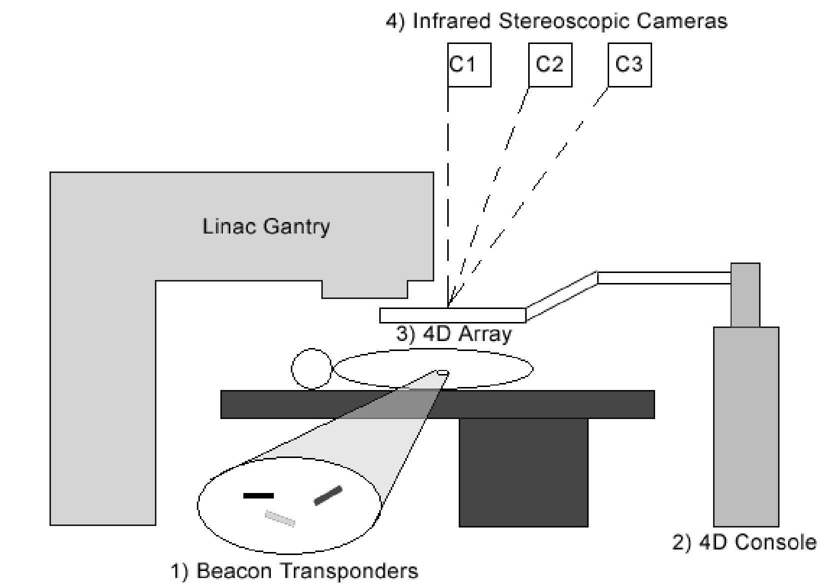


Figure 2: The Calypso Tracking System. Beacon transponders are implanted in the patient (1). They are tracked via the 4D Array mounted to the 4D console (2,3). This information is sent outside the treatment vault to the 4D tracking station (not pictured) and the positions are registered to the room coordinate system via infrared tracking of the array (4)

electromagnetically tracked transponders (Beacon®, Calypso Medical) which offer similar benefits of the knowledge of a few discreet internal points without additional imaging dose.

The Calypso® 4D Localization System uses Beacon® transponders which are approximately 8 mm in length (Figure 2). The transponders are currently FDA approved for use in the prostate; but the system is designed for body-wide use. In practice, the patient has the transponders implanted near the area to be irradiated. At time of treatment, the Calypso 4D Console™ is placed next to the treatment couch, and the Calypso 4D Electromagnetic Array™ is aligned on top of patient (Figure 3). This sends tracking information to the therapist outside of the treatment room at the Caypso 4D Tracking Station™. The array is aligned to the room coordinate system via infrared imaging devices mounted on the ceiling of the treatment room. With the commercial system, up to three transponders can be tracked at a refresh frequency of 10 hz.

The Calypso system has been proven useful for initial alignment of the patient on the treatment couch prior to irradiation, as well as tracking the prostate during radiation therapy for prostate cancer. It provides the therapist fast access to the position information without the need to leave the room.
The alignment of continuously moving lung tumors may be more challenging. It will be necessary to localize the spine and evaluate for tumor change on a regular basis. Electromagnetic tracking has high temporal resolution, and a sub-millimeter spatial resolution. There is a need to create a software platform to quickly and efficiently display the relationship of the electromagnetic transponders to previously acquired volumetric imaging. Here we show the development of a software system for visualization and representation of 4DCT images with Calypso Beacon trajectories overlaid. Potential applications as well as the software development process are discussed.

## 2 Methods

Under an animal studies approved protocol[7], three transponders were bronchoscopically implanted into the periphery of the lungs of four dogs (Figure 3a). On separate measurement days, the dogs were anesthetized and intubated. An external pneumatic bellows previously shown to be correlated to tidal volume was placed around the dog's thorax and sampled at 100Hz. The

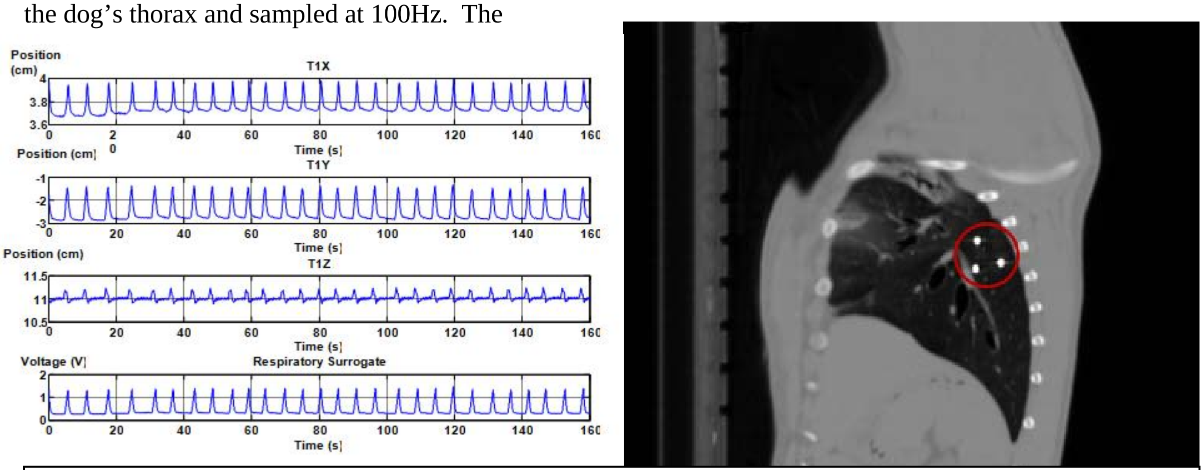


Figure 3. A) 3D position information obtained from a single implanted Calypso Beacon and correlated with the signal obtained from a respiratory surrogate.
B) Sagital view of electromagnetic transponders bronchoscopically implanted in the lung of a canine. Note that the transponders contain metal and as a result they are easily visible on a CT or fluoroscopic scan.

transponder positions were sequentially measured every 50ms using a wireless tracking system simultaneously with the respiratory surrogate measurements (Figure 3b). The dogs were imaged on a Phillips Brilliance 16 slice scanner for 25 frames at each of the 16 couch positions and this image information was reconstructed into 4DCT image sets using the Washington University percentiles algorithm coupled with the waveform from the respiratory surrogate. The implanted transponders are visible in the 4DCT image set.

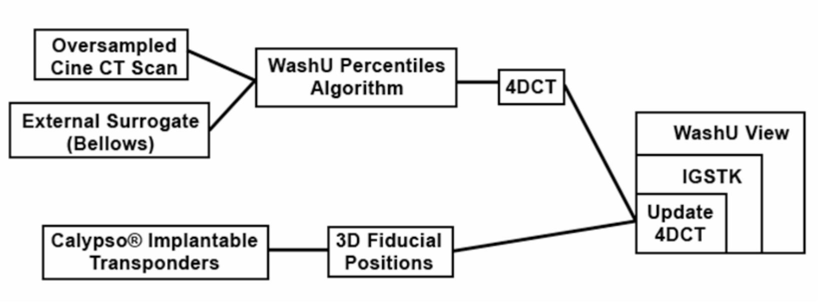
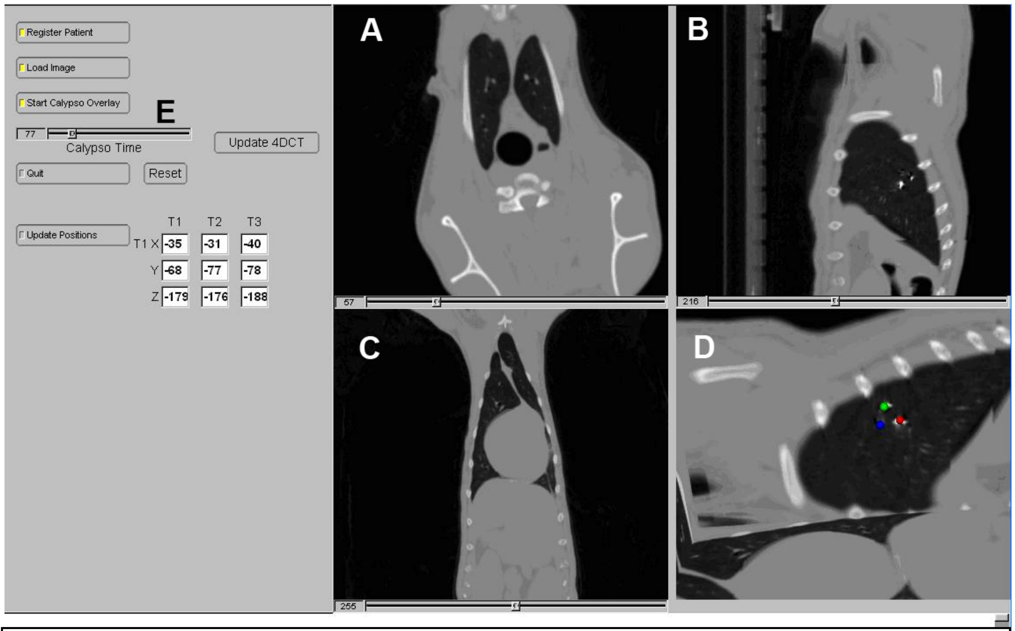


Figure 4. Block diagram of the WashU View software. 4DCT image data and transponder positions are read into the software for visualization.

A software application was created in order to visualize the acquired transponder position data coupled with the volumetric 4DCT image sets. As evidenced in the block diagram (Figure 4), 4DCT information is acquired via an oversampled ciné CT scan and a respiratory surrogate. The Washington University Percentiles algorithm is used to reconstruct the data as described in the introduction. This 4DCT dataset is read into the software, along with the position information recorded from the Calypso Beacon transponders while the canine is breathing under ventilation. The software platform was developed using the Image Guided Surgery Toolkit (IGSTK.org) which provides a high-level object oriented state machine architecture for rapid deployment of image display applications. The Washington



|  | T1 | T2 | T3 |
|---|---|---|---|
| T1 X | -35 | -31 | -40 |
| Y | -68 | -77 | -78 |
| Z | -179 | -176 | -188 |

Figure 5. Screen shot of the WashU View software. Axial (a), sagittal (b), and coronal (c) cross sections are displayed. In addition, a 3D viewing window (d) shows all slices along with the transponders from arbitrary angles. The transponders can load position information from a given time via a slider (e)

University viewing software displays axial, coronal, and sagittal images along with the 3D image window that can be viewed from any angle (Figure 5). Calypso Beacon® transponder trajectories can be loaded into the software and independently addressable visual indicators overlay the 3D representation to show transponder position. The software provides an interface for initial registration between the baseline maximum exhalation 3D CT image and the transponder positions. After registration is performed, the user can scroll through time and the overlaid transponders will move to display their corresponding position. Based on this position, all four image representation windows can be updated at the click of a button to display the corresponding breathing phase image set of the 4DCT that most accurately represents the given transponder positions.

## 3 Discussion

Treatment planning, patient imaging, dose delivery, dose verification as well as many other aspects of radiation therapy can benefit from the consideration of respiratory motion. We have developed software infrastructure that provides a means for rapid evaluation of respiratory correlated volumetric imaging with known internal fiducial positions. This framework will be used to evaluate the effectiveness of respiratory correlated imaging, and whether internal transponders have shifted in between treatment planning/imaging and treatment delivery.

In order to assess level of correlation between respiratory correlated imaging and internal fiducial positions, we qualitatively analyzed data recorded from the canine 4DCT study. As evidenced in Figure 6, for many portions the transponder positions correlate well with the corresponding amplitude of the 4DCT image set. In other situations, there was considerable error between the electromagnetically measured internal fiducial position and the corresponding artifact found on the 4DCT.

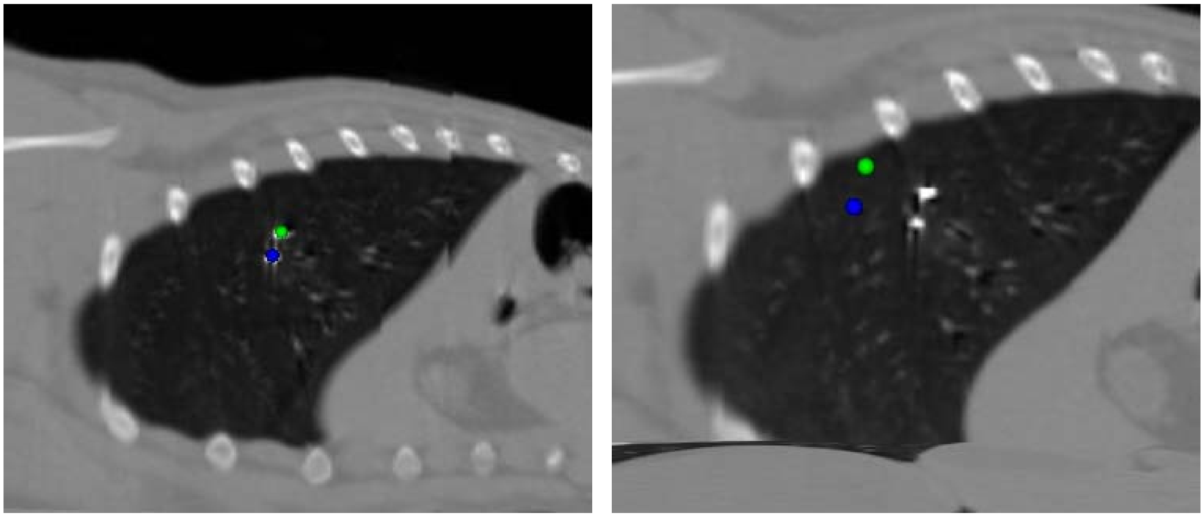


Figure 6. 4DCT images with Calypso transponder position overlaid in color. A) The imaged transponder positions match well with measured position later at maximum exhalation. B) The imaged transponder positions from maximum inhalation during 4DCT do not match maximum inhalation tracking data taken at a separate time point.

An ideal 4DCT dataset requires an infinite amount of images for each axial slice of the patient. This would provide enough data that the reconstructed 4DCT could bin the images into an infinitely small number of phases of the breathing cycle. Assuming that respiration is both reproducible and periodic, this results in more accurate correlation between internal position and volumetric imaging. With this said, increasing the number of samples for each axial slice also increases the imaging dose to the patient. There is an inherent tradeoff between imaging dose and the accuracy of respiratory correlated volumetric imaging. It stands to reason that there is a level in which reconstructing the 4DCT at additional phases/amplitudes grants little improvement in terms in internal position knowledge. In addition, more and more patient studies show that motion measured from preplanning 4DCT may not be valid throughout therapy.[8]

The framework provided by WashU View will allow for quick analysis and registration for future studies and experiments. The next application will be created for the therapist. We would envision that the therapist aligns the patient on the couch using the Calypso system. An EPID image is acquired after the patient is aligned on the treatment couch to illustrate the position of the spinal cord, which often is the dose limiting critical structure. This image is loaded into WashU View, along with a brief recording of the Beacon transponder positions. This information is displayed to allow the therapist to determine the need for more volumetric imaging (i.e. if the positions have changed due to tumor migration or gross breathing changes) versus delivering therapy. More work is needed to integrate electromagnetic tracking and volumetric imaging for efficient precision radiation therapy.

## 4 Acknowledgments

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