# A method for improved 4D-computed tomography data acquisition

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## Abstract

*In four-dimensional time-dependent computed tomography (4D-CT) of the lungs, irregularities in breathing movements can cause errors in data acquisition, or even data loss. We present a method based on sending a synthetic, regular breathing signal to the CT instead of the real signal, which ensures 4D-CT data sets without data loss. Subsequent correction of the signal based on the real breathing curve enables an accurate reconstruction of the size and movement of the target volume. This makes it possible to plan radiation treatment based on the obtained data. The method was tested with dynamic thorax phantom measurements using synthetic and real breathing patterns.*

**Keywords:** Irregular breathing, data loss free, 4D-CT, SABR, 4D-CT reconstructions, breathing monitoring

## Methodik zur verbesserten Datenerfassung bei der 4D-Computertomographie für die stereotaktische ablative Strahlentherapie

## Zusammenfassung

*Störungen der regelmäßigen Atembewegung des Patienten bzw. der Patientin während der Durchführung einer zeitaufgelösten Computertomographie (4D-CT) der Lunge führen zu Fehlern in den generierten Bilddaten, oder sogar zu Datenverlusten. Wird anstelle des realen Atemtsignals ein künstlich erzeugtes, regelmäßiges Signal an den CT gesendet, kann eine datenverlustfreie Aufnahme garantiert werden. Nachträgliche Korrektur der Trigger, anhand der Auswertung der realen Atemkurve ermöglicht eine volumenkorrekte Rekonstruktion der Bilddaten, so dass eine Bestrahlungsplanung möglich ist. Die Methode wurde mithilfe eines dynamischen Thorax Phantoms anhand von künstlichen und realen Atemkurven getestet.*

**Schlüsselwörter:** Unregelmäßige Atmung, Datenverlustfrei, 4D-CT, SABR, 4D-CT Rekonstruktionen, Atmungserkennung

## Introduction

Radiation therapy is one of two treatment options for pulmonary carcinoma. Technological progress in this area has led to a significant improvement of results, and one key development has been the ability to model the target volume taking account of the movement of the tumour as the patient breathes, using computed tomography (CT) [1]. This involves

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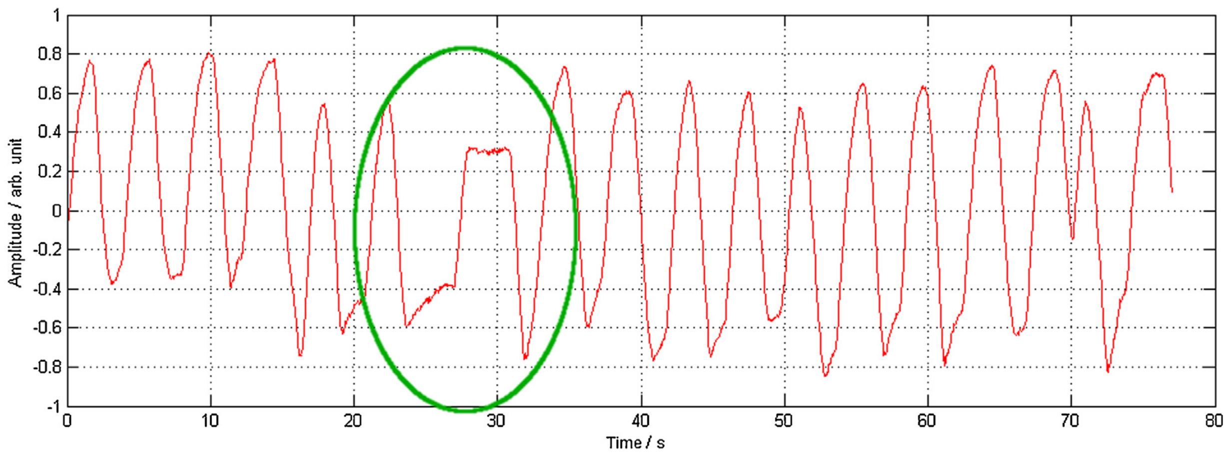


Figure 1. Excerpt of the recording of the breathing movements of a patient during a 4D-CT scan. The green oval marks the period in which a data loss occurred.

generating time-dependent CT data sets which capture the breathing movement as the 4th dimension (4D-CT). Subsequent sorting of the data allows the reconstruction of individual breathing phases [2]. However, this type of 4D-CT image of the lungs is vulnerable to significant errors if the patient's breathing is not regular [2–6]. Irregularities in breathing have unpredictable effects on the captured data, independent of their magnitude [7]. It is possible to have significant irregularity of breathing throughout the recording period without loss of data; on the other hand a brief episode of coughing with otherwise regular breathing can cause a loss of data. If a loss of data occurs while the scan is passing a tumour region, information on the movement of the tumour is lost and the scan results are suboptimal or completely unusable for radiation therapy treatment planning [8]. Even if no data loss occurs, artefacts arising from irregular breathing can also cause errors in the measured volume of the target [9].

This paper presents a method for completely avoiding data loss and using the captured data to accurately reconstruct the target volume, so that the results can be used for treatment planning and so that repeat scans, which are time-consuming and expose the patient to additional radiation, can be avoided. It should be noted, that repeated scans are not a guarantee for a successful data acquisition. Further, with our method the functioning of the existing systems is not altered and the data processing and data path are not changed. Similar systems using an external gating system [10] should also benefit from this method independent of the CT vendor.

## Methods

### Conventional method

4D-CT acquisition works conventionally with real-time monitoring of breathing movements during the CT scan [3,11] usually based on detecting periodic features such as a certain amplitude or a particular phase of the respiratory cycle. In case of the lungs a predictive signal at the peak of inspiration preferably in the phase based mode, is sent to the CT scanner, which continuously acquires multiple data at each image position with a low pitch predefined by the patient's breathing cycle. Afterwards, the oversampled CT raw data are retrospectively sorted in respiratory bins according to the couch position and signal coherence with predefined respiratory phases. For strictly periodic movement this method is best suited for an accurate reconstruction. Since breathing curves rarely resemble sine curves, inspiration and expiration periods may vary in length and in case of an irregularity/phase shift the breathing monitoring system fails to send a signal. As long as the respiratory signal fails data are not linked to a breathing cycle and are discarded, which is referred to as a loss of data [9], as can be seen in Fig. 1. According to Rietzel and Chen [2], errors in recognition of the breathing movements occur in about 30% of all scans.

### Scan mode

All scans were acquired using a multislice helical CT (Toshiba Aquilion LB V.3). For all data acquisition a clinically standard protocol (120 kV, 150 mA, Rot.T.: 0.5, FOV: 700, Reconstr. Intervall: 2 mm) was used. It was investigated and found that the scan parameters do not influence the functionality of the developed method.

### Breathing monitoring system

Breathing detection was performed with the Varian Real-Time Position Management respiratory gating (RPM) system. The RPM system monitored the breathing movements using a marker block detected by an infrared camera and sent a marker signal to the CT scanner if the maximum inspiration peak was reached. The RPM signal was replaced by a signal generated with a C-Control PRO Mega 128 processor on a C-Control