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Case Study for Real-Time Modeling of Breathing Amplitude for Lung SBRT

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Abstract
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Abstract

Objective: The purpose of this work is to present an innovative model for breathing amplitude that can accurately predict phase in real-time. Current retrospective phase calculations based on measured breathing period at the end of the cycle are unreliable during the actual cycle. Gated and MLC/jaw tracking for lung SBRT often depend on knowing the current breathing phase. Consequently incorrect phase determination can result in dose delivery errors.

Methods: A representative sample of the patient breathing pattern including irregularities was obtained prior to treatment with an optical marker on the abdomen. The amplitude minimum corresponding to end of cycle and the peak value are the only two parameters that are observed reasonably accurate in real time. This work will demonstrate that knowing the start on a new cycle, the time to reach maximum value, and amplitude monitoring can accurately predict the end on the cycle and consequently determine phase in real time. Three cycles having approximately the same "normal" period, one cycle having a relatively "short" period, and one cycle with an "extended" period were selected for modeling using a cubic polynomial as a function of phase. The phase itself was modeled as a linear function of time from the last cycle for each of the three cycle types. To test the model the sample breathing pattern was run in real time. At every time interval the measured amplitude was compared to each of the three models by first computing the phase as a function of time elapsed since the end of the last cycle and then computing the amplitude as a function of phase. The difference between the measured amplitude and each model for time t was denoted as Dn(t) for normal, Ds(t) for short, and De(t)for extended. The corresponding sum of differences added from the beginning of the cycle for each type is SDn(t), SDs(t), and SDe(t). The hypothesis is that the model with the least error is the best estimate for the current phase.

Results: The instantaneous error is a poor indicator of a valid model since in a complex irregular breathing pattern the error is subject to rapid fluctuations and the error curves for the three models often cross each other.Running sums of the error for a fixed period prior to the current time improved accuracy but were still unreliable in several instances. Accuracy improved as the prior interval was increased. As would then be expected the most accurate results were obtained when the error sum started at the beginning of the cycle and extended to the current type. Using this metric the current phase was correctly identified within +/- 10%. Using standard retrospective measurements the error was as high as +/- 20%.

Conclusion: The model presented indicates improved real time accuracy compared to existing retrospective calculations. Further testing and data collection is needed prior to robust clinical implementations. Using a large data set the model can also train AI systems to recognize erratic patterns and associate them with the correct phase.