Respiratory motion compensation in radiotherapy

Tomas Krilavičius[1,2,a], Indrė Žliobaitė[2,3,b], Henrikas Simonavičius[4,c] and Rūta Užupytė[1,2,d]

[1]Vytautas Magnus University, Vileikos str. 8, LT 44404, Kaunas, Lithuania

[2]Baltic Institute of Advanced Technology, Saulėtekio str. 15, LT 10224 Vilnius, Lithuania

[3]Dept. of Computer Science, Aalto University, P.O. Box 15400, FI-00076 Aalto, Finland

[4]Rubedo Systems, UAB, Jovarų str. 2, LT 47193, Kaunas, Lithuania

[a]t.krilavicius@bpti.lt, [b]indre.zliobaite@aalto.fi, [c]henrikas.simonavicius@rubedo.lt, [d]ruta.uzupyte@bpti.lt

Keywords: respiratory motion compensation, predictive modeling, real-time.

Abstract. The goal of this study is to develop a prototype for compensating respiratory motion in radiotherapy by the position of a couch. It requires predicting a position of the tumor and moving the couch (patient) into the required position. In this study we propose algorithms based on exponential smoothing for predicting a position of an external marker, generalized least squares method for multiple linear regression and prototype based on HexaPOD evo couch, NDI Polaris infrared stereo camera and in-house software developed by Rubedo Systems.

Introduction

The goal of radiotherapy treatment is to destroy the tumor and at the same time prevent the healthy surrounding tissues from being damaged. Advances in radiotherapy technologies have made highly conformal and accurate treatment possible [1-4, 7, 8]. However, the ability to aim the radiation beam at the target with minimal error is an important limiting factor [1-4]. Consequently, motion management is an active research and development topics in modern radiotherapy [1-4].

Intrafraction motion (motion of the target during treatment) is usually caused by the skeletal muscular, cardiac, gastrointestinal and respiratory systems and target usually moves in a different way and magnitude depending on its location and fixation to the surrounding structures, and different patients. Lung tumors can move up to 3 cm in the cranio-caudal direction during normal respiration [1]. We report a prototype solution for the problem: algorithms for predicting motion from an external marker, predicting tumor position from an external marker position and implementation of 2D respiratory motion compensation using HexaPOD evo couch in combination with NDI Polaris infrared stereo camera [5,6] and implementation of the proposed algorithms.

Prediction of tumor motion

A number of different approaches can be used for prediction motion of functional target [1-4, 8-9], such as Artificial Neural Networks (ANN), regressions, state based probabilistic approaches, Kalman filters, multi-step linear prediction (MULIN), autoregressive moving average models (ARMA), seasonal autoregressive models (TVSAR), wavelet- based multi-scale autoregression (wMLS) and other [1, 4]. The models are evaluated by measuring the absolute disposition error as well as fluctuations of the prediction signal (jitter) [4] that basically describes an additional motion to be performed by the couch. We propose using ExSmi, a combination of modified exponential smoothing methods (simple exponential smoothing (ES1), double exponential smoothing that includes trend (ES2) and Holt-Winters or triple exponential smoothing (ES3) that includes seasonality). ExSmi has an online preprocessing for outliers removal, online fixed duration calibration and switch prediction phase, and a switching mechanism between the main model and a simple, but more robust baseline. Performance is evaluated, using, both prediction error and jitter. Experimental results show that method performs as well as other techniques or better wrt both performance measures, and at the same time is transparent and had fixed warm-up period.

Prediction of position of tumor from an external marker position

Usually, during radiotherapy session it is not possible to monitor a positon of tumor, therefore its position should be predicted from an external marker. A number of different techniques, such as ANN and different versions of regressions are used to estimate tumor position from an external marker. We have chosen generalized least squares method for multiple linear regression [7-8].

Prototype

Technical part of prototype setup is depicted in Fig. 1. It implements 2D versions of both algorithms and deploys HexaPOD evo couch, NDI Polaris infrared stereo camera. The results seem quite promising, i.e. system is capable of tracking moving dummy with pre-recorded motion. However, further experiments are necessary to develop stable prototype and test it using techniques that allow recording more information about motion and radiation.

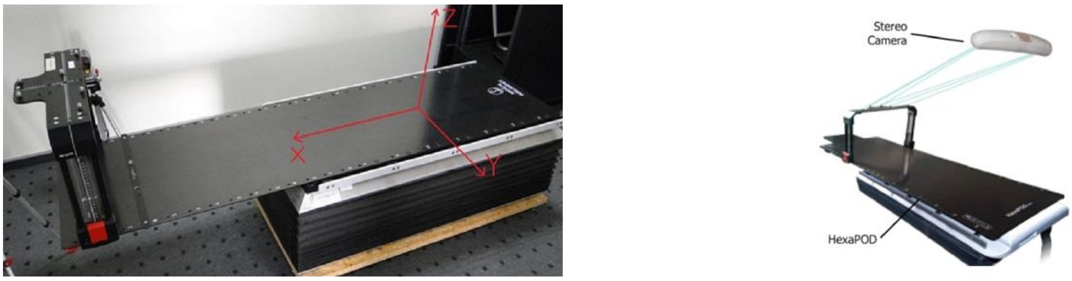

Fig. 1 System Setup

Conclusions

The proposed approach seems very promising, i.e. it deals quite well with different respiratory motion modes, has rather low jitter and positioning errors. However, further research and experiments are required to develop a system ready for usage in clinical conditions.

Acknowledgements

We thank G. Čaplinskas and L. Jaruševičius for the comments and ideas.

References

[1] P. J. Keall, G. S. Mageras, J. M. Balter, R. S. Emery, et al., The mgmt. of respiratory motion in radiation oncology rep. of AAPM Task Group 76, Med. Phys. 33 (10) (2006) 3874–3900.

[2] I. Buzurovic, K. Huang, Y. Yu, T. K. Podder, A robotic approach to 4D real-time tumor tracking for radiotherapy, Phys. in Med. and Biol. 56 (5) (2011) 1299–1318.

[3] D. Ionascu, S. B. Jiang, S. Nishioka, H. Shirato, R. I. Berbeco, Internal-external correlation investigations of respiratory induced motion of lung tumors, Med. Phys. 34 (2007) 3893.

[4] F. Ernst, R. Durichen, A. Schlaefer, A. Schweikard, Evaluating and comparing algorithms for respiratory motion prediction, Phys. in Med. and Biol. 58 (11) (2013) 3911–3929.

[5] T. Krilavičius, D. Vitkutė-Adžgauskienė, K. Šidlauskas, Simulation of the radiation therapy system for respiratory movement compensation, Jrnl. of Vibroengineering 14 (2012) 99–104.

[6] K. L. Man, T. Krilavičius, K. Wan, D. Hughes, K. Lee, Modeling and analysis of radiation therapy system with respiratory compensation using Uppaal, Proc. of the 9th IEEE Int. Symp. on Parallel and Distributed Processing with Applications Workshops (2011) 50–54.

[7] T. Krilavičius, R. Užupytė, I. Žliobaitė, H. Simonavičius, Correlation of external markers and functional targets for respiration compensation in radiotherapy, Med. Phys. in the Baltic States, 2013, pp. 42–45.

[8] R. Užupytė, K. Man, T. Krilavičius, I. Žliobaitė, H. Simonavičius, Indirect tracking of functional target for respiration compensation in radiotherapy, in: Proc. of IMECS, 2015