Chapter 20
Applications of Machine Learning in Real-Time Tumor Localization

Ruijiang Li
Stanford University, USA

Steve B. Jiang
University of California San Diego, USA

ABSTRACT

Recently, machine learning has gained great popularity in many aspects of radiation therapy. In this chapter, the authors will demonstrate the applications of various machine learning techniques in the context of real-time tumor localization in lung cancer radiotherapy. These cover a wide range of well established machine learning techniques, including principal component analysis, linear discriminant analysis, artificial neural networks, and support vector machine, etc. Respiratory gating, as a special case of tumor localization, will also be discussed. The chapter will demonstrate how domain specific knowledge and prior information can be useful in achieving more accurate and robust tumor localization. Future research directions in machine learning that can further improve the accuracy for tumor localization are also discussed.

INTRODUCTION

Radiotherapy is a major modality for treating cancer patients. In lung cancer, the tumor can move significantly due to respiratory motion. This sets a limit on the amount of radiation dose that can be prescribed to the patient without causing severe damage to normal lung tissues. A promising solution to this problem is real-time tumor tracking, a method to dynamically target the tumor with the radiation beam, allowing a reduction in the volume of healthy tissue exposed to a high dose. A prerequisite for effective tumor tracking is to know the tumor location in real time. Therefore, real-time tumor localization is essential for accurate dose delivery and thus enhancing the therapeutic ratio of radiotherapy.

DOI: 10.4018/978-1-4666-0059-1.ch020

In this chapter, we first describe the existing imaging modalities that are available for the purpose of real-time tumor localization. These include kilo-voltage (kV) fluoroscopy, (mega-voltage) MV imaging, electromagnetic (EM) transponders, fast MRI, 3D ultrasound, respiratory monitoring devices. We then focus on the tumor localization using kV fluoroscopy due to its decent image quality and wide acceptance in medical linacs for radiotherapy. In reviewing the machine learning techniques for real-time tumor localization, we first introduce respiratory gating as a special case, which can be formulated as a binary classification problem. We then discuss the tumor localization problem which can be formulated as a regression problem. We also demonstrate how prior information can be used to achieving more accurate and robust tumor localization. Finally, we point to some future directions in machine learning that can further improve the accuracy for tumor localization.

BACKGROUND

Respiratory motion affects all tumor sites in the thorax and abdomen, *e.g.*, lung, liver, breast, pancreas, *etc.* The disease of most prevalence for radiotherapy is lung cancer, which accounts for 29% of all cancer deaths in the U.S. (American Cancer Society Cancer Facts and Figures, 2009). Every day, approximately 439 Americans die from lung cancer. (American Cancer Society Cancer Facts and Figures, 2009). In fact, more people die from lung cancer each year than breast, prostate, colon, liver, kidney and melanoma cancers combined. The treatment outcome of the current modalities for lung cancer has been poor; the five-year survival rate for all stages combined is 15%. (American Cancer Society Cancer Facts and Figures, 2009). Radiotherapy is a major modality for treating cancer patients, either alone or combined with surgery and chemotherapy. Studies have shown that an increased radiation dose to the tumor will lead to improved local control and survival rates. However, because tumors can move significantly (~2-3 cm) with respiratory motion, it is very difficult for existing radiotherapy techniques to deliver sufficient radiation dose without damaging the surrounding healthy tissue and causing severe side effects such as pneumonitis in lung cancer patients (Jiang, 2006).

A promising solution to this problem is tumor tracking, a method to dynamically target the tumor with the radiation beam, allowing a reduction in the volume of healthy tissue exposed to a high dose. For radiotherapy based on medical linear accelerators, it can be implemented by tracking the tumor using a dynamic Multi-Leaf Collimator (MLC) that shapes the radiation beam (Keall, Kini, Vedam, & Mohan, 2001). Given the current radiotherapy technology, it is sufficient to align the treatment MV beam with the overall position of the tumor (i.e., center of mass). In order for the radiation beam to follow the tumor, the location of the tumor must be known, with high precision (on the order of ~2 mm) and in real time (on a sub-second scale, preferably within half a second for respiration induced tumor motion). Therefore, real-time tumor localization is essential for accurate dose delivery and thus enhancing the therapeutic ratio of radiotherapy.

There are several medical imaging modalities that have been used for the purpose of real-time tumor localization, including radiography (both kV and MV), Magnetic Resonance Imaging (MRI), ultrasound, Radio-Frequency (RF) electromagnetic wave, optical, *etc.*. Due to the different nature of data acquisition of these imaging modalities, the sophistication of data processing required to achieve accurate real-time tumor localization can also be very different. In the following, we briefly review these imaging modalities for the purpose of real-time tumor localization.

For kV radiographic imaging systems (fluoroscopy), there are two categories: room mounted and gantry mounted. Room mounted x-ray imaging systems include the Mitsubishi/Hokkaido RTRT