A Fast Toboggan-based Method for Automatic Detection and Segmentation of Pulmonary Embolism in CT Angiography*

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Pulmonary embolism (PE), a potentially life-threatening condition, is a result of underlying venous thromboembolic disease. An early and accurate diagnosis is the key to survival. Computed tomography angiography (CTA) has merged as an accurate diagnostic tool for PE. However, there are hundreds of CT slices in each CTA study. Manual reading is laborious, time consuming and complicated by various PE look-alikes (false positives) including respiratory motion artifact, flow-related artifact, streak artifact, partial volume artifact, stair step artifact, lymph nodes, vascular bifurcation among many others[1, 2]. Clearly, this demands a CAD (computer aided diagnosis) tool which can assist radiologists in detecting and charactering emboli in an accurate, efficient and reproducible way [3–5]. In this communication, we report a fast yet effective toboggan-based approach for automatic, simultaneous PE detection and segmentation in CTA.

Our developed method is based on tobogganing [6]. In tobogganing, which takes its name from the processing analogy of sliding down a steep hill, each voxel slides to neighbors with the smallest original CT value. All voxels sliding down to the same location form a toboggan cluster with a unique label. In order to improve the efficiency of tobogganing, we have developed an algorithm called dynamic fast tobogganing, which starts from a specified location and quickly forms a toboggan cluster locally without involving any voxels beyond the outer boundary of the toboggan cluster. Each voxel is only processed once, leading to high efficiency.

For automatic PE detection, our tobogganing algorithm can be further accelerated based on the two following *a priori* knowledge of medical physics. First, in CTA images, the embolus appears as dark regions (see Figure 1) with Hounsfield Units (HU) between -50 HU and 100 HU. Therefore, we can effectively exclude all the voxels outside the range [-50 HU, 100 HU] and only need to slide the voxels inside this HU range to accelerate the tobogganing process.

Second, pulmonary embolism can only exist in pulmonary arteries, so we only need to search for PE within pulmonary arteries. However, arterial segmentation is computationally time-consuming and has been problematic in terms of accurate extraction in smaller vasculature where subsegmental PE often occur. Fortunately, the Hounsfeld density criterion ([-50 HU, 100 HU]) excludes areas above 100 HU in the arteries, therefore, large part of segmented arteries would be excluded in any case. Therefore, our technique permits the use of a fast and coarse overall lung segmentation as PE search region, bounded by the outer pleural surface, instead of an arterial segmentation.

At the completion of tobogganing, we collect all the toboggan clusters in the search region to form PE segmentations (see Figure 1), from which a single detection position is derived based on morphological ultimate erosion. In short, our approach includes these five steps: coarse lung segmentation, tobogganing, collecting toboggan clusters (forming PE segmentation) and identifying detection locations.

We should note that when only a coarse lung mask is used, it is crucial to properly handle partial volume artifacts around the vessel wall and around the airway wall, because all the voxels in those areas have the same original CT values as those in the PE regions. In the tobogganing process, almost all those voxels automatically merge into regions outside of the PE search region (below -50 HU), and are therefore automatically removed when collecting toboggan clusters.

We have collected 72 cases with 242 clots marked by expert chest radiologists at four different institutions (two North American sites and two European sites). They are divided into two sets: development (48 cases with 173 clots) and validation (24 cases with 69 clots). The

* Research prototype; not commercially available.

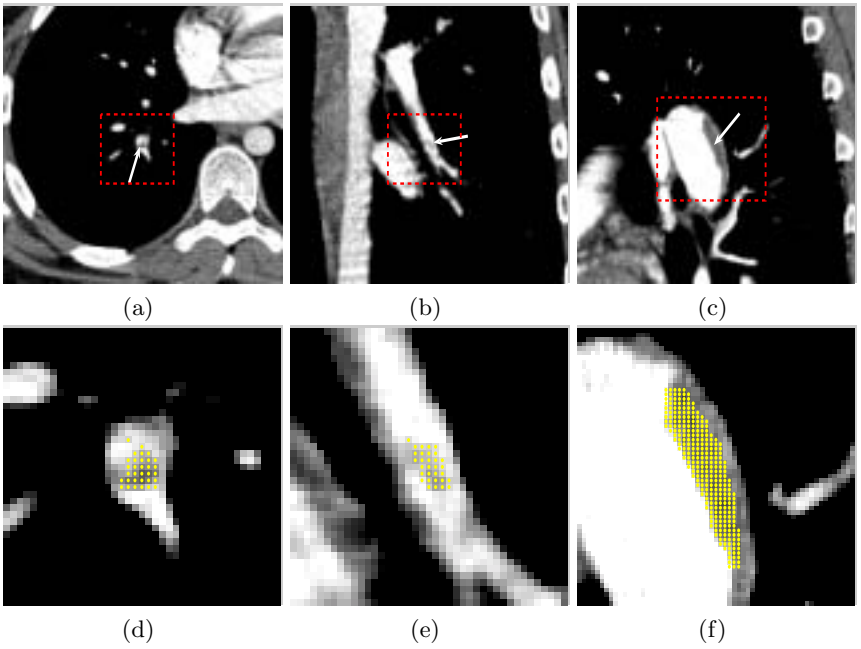

Fig. 1. Our toboggan-based approach is capable to detect both acute (a, b) and chronic (c) pulmonary emboli, offering simultaneous detection and segmentation (d, e, f). Please note that the clot in (b) was actually missed by our radiologist but correctly detected by our system.

development cases were used in the development process for algorithm developing, improving and testing, while the validation cases were only used for algorithm testing and were never used for development. Our algorithms successfully detected 94.2% (163/173) of the PE in the development cases and 95.7% (66/69) of the PE in the validation cases. The average computation time for each case is only about 2 minutes on a 2.4GHz P4 PC.

In summary, we have developed a toboggan-based method for automatic, simultaneous detection and segmentation of pulmonary embolism in contrast-enhanced CTA images. The developed method is capable to detect both acute and chronic pulmonary emboli. It utilizes the simple sliding operation in fast tobogganing and requires no vessel segmentation, resulting in high efficiency (only 2 minutes for each case). It offers simultaneous detection and segmentation, enabling automated computation of pulmonary embolism index. Given this high efficiency and high sensitivity, it is well suitable to employ as a PE candidate generator in a full PE CAD system. We are investigating PE-oriented candidate features to eliminate the false positives, which are mainly from the veins and lymphoid tissues but covered by the coarse lung mask.

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