Abstract ID 76

AUTOMATIC SEGMENTATION OF THE SPINE AND LOWER LIMBS BASED ON DEEP LEARNING IN LOW-DOSE BIPLANAR RADIOGRAPHS

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Keywords: Deep Learning, Segmentation, Low-dose X-ray, Biplanar radiographs, 3D Reconstruction, Spine, Lower limb

Summary: Three-dimensional subject-specific reconstruction of the spine and lower limbs based on low-dose biplanar X-rays is now available in clinical routine. These methods enable 3D visualization and quantification of 3D deformities such as scoliosis. Although the validity and reliability of these methods were already evaluated, these reconstructions require manual input and adjustments from well-trained operators. The reconstruction time is then significant, and therefore a hindrance for a large-scale use of such methods. Full automation is therefore of great interest. To that end, bone detection, classification and segmentation can be of tremendous value for replacing manual inputs. Segmentation methods exist for isolated bones, but a different framework is used for each bone. Therefore, we propose a single deep learning framework for joint detection, classification and segmentation of the spine and lower limbs. A database of 138 biplanar radiographs, with spine and lower limbs reconstructions, comprising of 20% of scoliotic patients was collected retrospectively. It was used to train and evaluate our method using a 5-fold cross validation. Ground truth segmentations of the spine, tibias and femurs were obtained by reprojection of the 3D models on the radiographs. The classification and segmentation was split into three separate steps through a coarse-to-fine approach. The first step consisted in the segmentation of the images at $1/4^{th}$ of the resolution. The obtained masks allowed an error-free calculation of bounding boxes for finer delineation of each structure. The second step consisted in the segmentation in the sagittal view of each lower limb with half resolution allowing the network to detect both femurs and tibias with better performance. Indeed, these segmentations were obtained with a mean Dice Similarity Coefficient (DSC) of 0.92 (mean SD = 0.07). The last step consisted of the segmentation of four subparts of the spine in full resolution: cervical, upper/lower thoracic and lumbar spine. At each step, we used nnU-net, a variant of the fully convolutional neural network U-net, which can automatically optimize hyperparameters. A mean DSC of 0.89 (mean SD = 0.06) and 0.92 (mean SD = 0.04) was obtained in the frontal and sagittal views respectively. To the best of our knowledge, this is the first automatic segmentation of both full spine (from C3 to L5) and lower limbs with a single framework. Our method obtained comparable results with the literature in a full body manner and can deal with severe scoliosis. The computational time for the prediction of the neural network was less than 10 seconds per image. From these segmentations, we can then gather structures and points such as the spinal midline and joint centers that are needed in the 3D reconstruction process. In clinical routine, a trained operator currently manually digitizes these points. The proposed method has then the potential to replace the tedious manual inputs for the 3D reconstruction of the spine and the lower limbs. Moreover, some of these results can be used to compute simple 3D radiographic parameters, especially in the lower limbs (e.g. Hip-knee angle, hip-knee-shaft angle…), and could potentially be used in quick, timesaving posture analysis.