Efficient Annotation and Deformation Prediction for Musculoskeletal Analysis Using Medical Image Datasets

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Abstract

Hip osteoarthritis (OA) remains a leading source of disability worldwide, underscoring the need for accurate musculoskeletal assessment to optimize patient outcomes. This dissertation proposes a two-part framework designed to (1) minimize the burden of manual annotations while achieving high segmentation accuracy, and (2) model femur shape changes linked to OA progression using rich geometric and clinical data.

In the first component, an active learning-based segmentation method leverages Bayesian uncertainty estimation and a hybrid sampling strategy to pinpoint the most informative images for annotation. By prioritizing representative yet diverse samples, this approach notably reduces the manual labeling workload. In the second component, a shape prediction module incorporates geometric encoding and patient-specific variables—such as demographics and OA severity—to capture subtle femoral deformations in large-scale CT datasets. The combined system highlights how bone morphology evolves under pathological conditions and can detect clinically relevant landmarks in the hip joint.

Validation on comprehensive lower extremity datasets confirms that the framework not only achieves robust segmentation with a substantially lower annotation cost, but also accurately predicts femoral head and neck changes associated with disease progression. These advancements open new avenues for personalized musculoskeletal care, enabling clinicians to anticipate structural deterioration, devise tailored interventions, and ultimately improve the long-term management of hip OA.