Bone Segmentation Report

For TASK 1.1

Femur and Tibia Segmentation from CT Images

Approach Overview

This solution segments femur and tibia bones from CT knee images using a multi-stage image processing pipeline. The approach combines intensity thresholding with morphological operations and anatomical knowledge to achieve robust bone separation.

Core Methodology

1. **Intensity Thresholding**: Applied 300 HU threshold to identify bone tissue based on typical cortical bone density
2. **Morphological Cleanup**: Used small object removal and binary closing to eliminate noise and fill gaps
3. **Spatial Analysis**: Analyzed each slice using connected component analysis to separate individual bone regions
4. **Anatomical Differentiation**: Distinguished femur from tibia using centroid-based spatial positioning

Robustness Features

The algorithm includes three fallback mechanisms:

- Adaptive thresholding (reduces threshold if initial segmentation fails)
- Anatomical region division (upper/lower volume separation)
- Spatial masking based on quadrant positioning

Solution Development

Why This Approach?

- **Constraint Compliance**: Image processing techniques only (no machine learning)
- **Medical Knowledge Integration**: Incorporates anatomical understanding of bone positioning
- **Reliability Focus**: Multiple fallbacks ensure consistent performance across varying image qualities

- **Computational Efficiency**: Fast, interpretable classical computer vision methods

Key Technical Decisions:

- 300 HU threshold based on medical imaging literature for cortical bone
- Morphological operations to handle CT imaging noise
- Slice-by-slice analysis for precise bone boundary detection

Results

The solution outputs segmented bone masks in NIfTI format with quantitative statistics and visual validation overlays, successfully separating femur and tibia regions while preserving spatial metadata for clinical use.

For Task 1.2 and 1.3

Creating Expanded and Randomized Bone Boundaries

What This Does

This tool takes the bone segmentation masks (femur and tibia) and creates two new versions:

1. **Expanded masks** - Makes the bone regions bigger by a specific amount (like adding a 2mm border around each bone)
2. **Randomized masks** - Creates irregular, natural-looking expanded boundaries instead of perfect uniform borders

Why We Need This

In medical imaging, we often need to:

- Create safety margins around bones for surgical planning
- Generate more realistic bone boundaries that account for natural variation
- Simulate different levels of bone expansion for analysis

How It Works

Step 1: Uniform Expansion

- Takes the original bone mask and grows it outward by 2mm in all directions

- Uses mathematical dilation (like inflating a balloon) to create smooth, even borders
- Converts the expansion distance from millimeters to image pixels based on scan resolution

Step 2: Random Boundary Creation

- Creates natural-looking, irregular boundaries instead of perfect circles
- Uses random values to decide how much each area should expand
- Ensures the result stays within the maximum 2mm limit but varies the actual expansion

Step 3: Smart Processing

- Automatically handles different file types and naming
- Preserves all the original scan information (spacing, orientation, etc.)
- Creates clearly labeled output files for easy identification

Technical Approach

The solution uses morphological operations (image shape manipulation) combined with distance calculations and randomization. It's like having a smart paintbrush that can grow shapes uniformly or create natural, varied edges while respecting physical limits.

Results

For each bone (femur and tibia), you get:

- Original segmentation
- Uniformly expanded version (perfect 2mm border)
- Randomly varied expansion (natural-looking irregular border up to 2mm)

This gives medical professionals multiple options for different applications, from precise surgical planning to realistic modeling of bone variations.

For task 1.4

Tibia Landmark Detection Report

Finding Key Points on Bone Surfaces

What This Does

This tool automatically finds important anatomical landmarks (key reference points) on the tibia bone from medical scans. Think of it like a GPS system that identifies crucial navigation points on the bone surface for medical procedures.

Why We Need Landmark Detection

Medical professionals need precise reference points on bones for:

- Surgical planning and navigation
- Measuring bone dimensions and angles
- Comparing different patients or tracking changes over time
- Ensuring consistent placement of implants or surgical tools

How It Works

Step 1: Create Multiple Bone Versions

- Takes the original tibia mask and creates 5 different versions
- Makes expanded versions (2mm and 4mm bigger borders around the bone)
- Creates randomized versions with natural, irregular boundaries
- This gives doctors options for different levels of precision

Step 2: Find Surface Points

- Identifies the outer surface of each bone version
- Like finding the exact edge of a 3D object by comparing it to a slightly smaller version
- Focuses only on the boundary points where the bone meets surrounding tissue

Step 3: Detect Key Landmarks

- Automatically locates two critical points on each tibia:
    - **Medial point**: The inner-side landmark (toward the body's midline)
    - **Lateral point**: The outer-side landmark (away from the body's midline)
- Converts pixel locations to real-world millimeter coordinates

Step 4: Compare and Document

- Shows how landmark positions change with different bone boundary definitions
- Creates a detailed table comparing all versions
- Saves everything for medical record keeping

Results

For each of the 5 bone versions, you get:

- Precise 3D coordinates of both landmark points
- Comparison table showing how boundary changes affect landmark positions
- Saved files ready for surgical planning software

This helps surgeons understand how measurement precision affects landmark detection and choose the most appropriate bone boundary definition for their specific procedure.