Gemini 3.0 Orthopedic Finite Math & Physics Report

System Version: 3.0.1
Module: Orthopedic Intelligent Guidance System (IGS)
Date: January 18, 2026

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1. Volumetric Image Acquisition (Acquisition Tab)

The acquisition module simulates the reconstruction of a 3D anatomical volume V from a set of 2D axial slices S_k.

1.1 Voxel Intensity Model

The intensity $I(x,y,z)$ of a voxel at position $\mathbf{p}=(x,y,z)$ is modeled as a function of tissue density $\rho(\mathbf{p})$ with additive Gaussian noise η:

$$I(x,y,z) = \alpha \cdot \rho(x,y,z) + \eta$$

Where: - $\rho(x,y,z) = \begin{cases} 200 & \text{if } \mathbf{p} \in \text{Cortical Bone} \\ 180 & \text{if } \mathbf{p} \in \text{Cancellous/Tibia} \\ 0 & \text{otherwise} \end{cases}$ - $\eta \sim N(0, \sigma^2_{noise})$

1.2 Region of Interest (ROI) Algebra

The segmentation masks for the medial and lateral condyles are defined by finite inequalities:

Medial Condyle:

$$(x - c_{medial})^2 + (y - c_y)^2 \le r^2_{condyle}$$

Tibial Plateau (Ellipsoidal):

$$\frac{(x - c_x)^2}{a^2} + \frac{(y - c_{y_{tib}})^2}{b^2} \le 1$$

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2. Quantum Geodesic Registration (Registration Tab)

Registration aligns the intra-operative tracker coordinate frame $F_{tracker}$ with the pre-operative CT/MRI frame F_{CT}. The system utilizes a “Quantum Geodesic Mapping” approach, represented as an iterative optimization of a rigid body transformation T.

2.1 Transformation Matrix

The transformation $T \in SE(3)$ is defined by a rotation matrix R and translation vector $\mathbf{t}$:

$$T = \begin{bmatrix} R & \mathbf{t} \\ 0 & 1 \end{bmatrix}$$

Where R is constructed from Euler angles (ϕ, θ, ψ):

$$R = R_z(\psi) R_y(\theta) R_x(\phi)$$

2.2 Cost Function Optimization

The objective is to minimize the Root Mean Square (RMS) error between the source point cloud $P = p_i$ and target cloud $Q = q_i$:

$$E(R, \mathbf{t}) = \sum_{i=1}^{N} (Rp_i + \mathbf{t}) - q_i^{\,2} + \lambda \int_{\Omega} \Psi_{geodesic} \, d\Omega$$

The "Evolutionary Propagation" simulates the gradient descent steps:

$$Error_{k+1} = \gamma \cdot Error_k + \varepsilon$$

2.3 Repeatability Statistics

For N trials, the repeatability confidence score S is derived from the standard deviation σ_{rms} of the final convergence error:

$$S = 100(1 - \kappa \cdot \sigma_{rms})$$

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3. Conformal Surgical Planning (Planning Tab)

The planning engine generates resection profiles $Y_{cut}(x)$ to match the inverse geometry of the implant $Y_{implant}(x)$.

3.1 Anatomy Polynomial Approximation

The distal femur curvature is approximated by a parabolic function:

$$Y_{native}(x) = -\frac{x^2}{2R} + H_0$$

3.2 Resection Geometry (Chamfer Cuts)

The resection profile is a piecewise function defining the 5-cut technique:

$$Y_{cut}(x) = \begin{cases} -5 & |x| < 20 \quad \text{(Distal)} \\ -10 - (|x| - 20) & 20 \le |x| < 35 \quad \text{(Chamfer)} \\ -25 & |x| \ge 35 \quad \text{(A/P)} \end{cases}$$

3.3 Posterior Stabilized (PS) Cam Mechanism

For PS implants, a "box cut" requires a modification in the central domain $D_{box} = x : |x| < 10$:

$$Y_{PS\_cut}(x) = Y_{cut}(x) + \delta_{box} \cdot \mathbf{1}_{D_{box}}(x)$$

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4. Ligament Balancing Kinematics (Planning Tab)

Kinematics are simulated as a function of flexion angle $\alpha \in [0, 145]$.

4.1 Gap Functions

The varying gap distance $G(\alpha)$ between femur and tibia is modeled as:

Medial Compartment (Stable):

$$G_{med}(\alpha) = G_{target} + A_m \sin(k_1 \alpha) + \varepsilon_m$$

Lateral Compartment (Laxity allowed):

$$G_{lat}(\alpha) = G_{target} + A_l\left(\frac{\alpha}{\alpha_{max}}\right) + A_2 \sin(k_2 \alpha)$$

The **Safe Zone** is defined as the interval $[9.0, 11.0]$ mm.

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5. Implant Fit Optimization (Implant Fit Tab)

The “Quantum Surface Integral” calculates the fit energy between the implant mesh M_{imp} and the bone surface S_{bone}.

5.1 Energy Minimization

$$E_{fit} = {}_S\left(\mathbf{n}_{imp} \cdot \mathbf{n}_{bone}\right) e^{-dist(\mathbf{p}_{imp}, \mathbf{p}_{bone})^2}\, dA$$

Convergence history follows a quadratic decay:

$$E(t) = -t^2 \quad \text{(idealized)}$$

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6. Monte Carlo Post-Op Analytics (Post-Op Tab)

Outcomes are predicted using stochastic simulation over $N = 5000$ virtual patients.

6.1 Distribution Models

- **Flexion Range:** $X_{flex} \sim N(125, 10^2)$ truncated to $[90, 150]$.
- **Tibial Slope:** $X_{slope} \sim N(5, 1.5^2)$.
- **Cost Function:**

$$C_{total} = C_{base} + \delta + I(X_{flex} < 100) \cdot C_{penalty}$$

Report generated by Gemini 3.0 Agentic Framework.