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Quantum Solutions to Orthopedic Treatment Challenges in India: A Computational Approach to Accessibility and Personalization

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Abstract:

India's orthopedic healthcare system grapples with spatial disparity, economic constraints, and the need for individualized care pathways. We present a quantum-enhanced multi-objective optimization framework that formalizes orthopedic treatment planning as a hybrid classical-quantum decision model balancing accessibility, affordability, and treatment efficacy.

We begin by modelling the total care cost as a summation of weighted factors:

$$\text{argmax}_T U(H,T) - \sum_{j=1}^{m} w_j \cdot f_j(H,T)$$

Where:

- $f_j(H,T)$ measures outcome utility (mobility, pain reduction, etc.),
- w_j is the clinical weight of the outcome for patient j,
- $U(H,T)$ is the treatment utility function.

We encode the treatment selection optimization into a QUBO problem for quantum solvers:

$$\min_x x^T Q x + c^T x$$

Where:

- $x \in \{0,1\}^n$ is the treatment decision vector,
- $Q \in \mathbb{R}^{n \times n}$ encodes pairwise cost and compatibility penalties,
- c includes linear components (individual treatment penalties, region-based availability, etc.).

We further impose a budget constraint:

$$\sum_{i=1}^{n} x_i \cdot P_i \leq B$$

And a regional accessibility constraint:

$$\forall i \in \mathcal{R}, A_i \cdot x_i \geq \delta$$

Where:

- B is the patient or government-allocated budget,
- A_i is an accessibility score (urban: high, rural: low),

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- δ is the minimum acceptable threshold of accessibility.

We define a quantum-enhanced composite objective:

$$\max_x \Phi(x) - \omega_1 \cdot \left(\frac{U(H,T)}{C_{\text{total}}}\right) + \omega_2 \cdot P_s + \omega_3 \cdot A_s$$

Where:

- P_s = personalization score,
- A_s = accessibility satisfaction,
- ω_i are tunable policy weights.

Results:

Using a D-Wave Advantage hybrid solver with simulated patient clusters (urban, peri-urban, rural), our experiments yield:

- Reduction in cost: $\Delta C = 27\%$ (rural), 18% (urban)
- Accessibility improvement: $A_s \uparrow 41\%$ in Tier- 2/3 cities
- Personalization gain: $P_s \uparrow 36\%$ vs classical scheduling models
- Runtime improvement: Quantum solver reduced planning time from 300 s to 12 s (average)

These results validate quantum computing's role in solving high-dimensional, resource-constrained healthcare planning problems in India, enabling precision orthopedic treatment under real-world economic and logistical constraints.

Biography



Tarun Jaiswal is a Research Scholar at the Department of Computer Applications, National Institute of Technology, Raipur. His research interests include Machine Learning, Artificial Intelligence and IoT. He has published several research papers in leading national and international journals, as well as presented his work at various conferences. He has also worked on several projects related to Machine Learning and healthcare, which has given his practical experience in applying theoretical concepts to real-world problems. He has published more than 25 research articles in National and international journal. He has more than 100 patent and 30+ copyright and He is an author of 10+ books. His research is centered on Machine Learning, IoT, Artificial Intelligence and Healthcare.



Sushma Jaiswal is an Assistant Professor (CSIT), Guru Ghasidas Central University, Bilaspur, (C.G.). She has completed Ph.D. in the field of Image processing. She has teaching experience of 21 years and she has published many papers in various national and international journals as well as presented her work at various conferences. She has published more than 150 research articles in National and International journals. She acquired

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Issue 4

an astounding 155 patents national and international (Published and Granted), 45 Copyright national and international (Granted) and She is an author of 40+ books. She received the award of best women scientist, award of excellence in research, best faculty award, best teacher's award, numerous fellowship and many more. She is Editor and Reviewer of Several Reputed national and international Journals. She is a member of Ek Bharat Shrestha Bharat program, program office national social service (NSS), Antiaging, Research Committees etc. Her research is centered on Machine Learning, 3D Digital Image Processing, Computer Graphics, Healthcare and Traditional Indian indigenous knowledge. She is passionate about new innovations assisting persons with disabilities, particularly in mobility and education. She delivered expert talks and lectures at many conferences and received an invitation from national and international organization to deliver the lecture.

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ISSN: 2324-8602

Volume 10
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About Research Topic

India, with its vast and diverse population, faces serious challenges in delivering equitable orthopedic care—especially in rural and economically underserved regions. The rising incidence of musculoskeletal disorders, injuries, and age-related orthopedic conditions has put immense pressure on an already overburdened healthcare system. In particular, the issues of accessibility, affordability, and individualized treatment planning remain significant hurdles. Traditional healthcare models struggle to dynamically adapt to patient-specific needs while also optimizing for cost and geographical constraints.

This research explores how quantum computing—a paradigm shift in computational science—can revolutionize orthopedic treatment planning. Unlike classical algorithms, quantum approaches like Quantum Annealing and QUBO (Quadratic Unconstrained Binary Optimization) provide powerful tools to handle complex, large-scale optimization problems in real time. By modeling the orthopedic decision process as a multi-objective constrained optimization problem, quantum algorithms can simultaneously evaluate thousands of treatment possibilities, geographical locations, financial constraints, and patient health parameters to suggest the most optimal, personalized care strategy.

The research integrates:

- Patient-specific health models,
- Cost-access-distance analytics, and
- Outcome prediction models into a quantum-optimized framework.

The objective is not only to enhance the efficiency and accuracy of treatment planning but also to ensure that high-quality orthopedic care becomes accessible and affordable across India's tier-1 to tier-3 cities and rural belts.

This study also highlights the potential of quantum technology in India’s digital health infrastructure, aligning with national initiatives such as Ayushman Bharat Digital Mission and the National Quantum Mission, and sets the stage for real-time AI-quantum integrated clinical decision-making systems.

About Institution:

Guru Ghasidas Vishwavidyalaya (GGV), located in Bilaspur, Chhattisgarh, is one of the largest and oldest institutions of higher education in central India. Established in 1983 and later declared a Central University under the Central Universities Act 2009, GGV is named after the revered saint Guru Ghasidas, a great social reformer who championed equality, social justice, and education for all.

The university spans a lush green campus of over 650 acres and serves as a hub for academic excellence, research innovation, and societal development. With 11 schools of studies and over 32 departments, the university offers a wide range of undergraduate, postgraduate, and doctoral programs in disciplines including Engineering & Technology, Natural Sciences, Social Sciences, Humanities, Management, and Education.

GGV is committed to fostering a research-driven environment and promoting interdisciplinary collaborations. The institution emphasizes inclusive education, skill development, and innovative research, aligning itself with national missions like Digital India, Atmanirbhar Bharat, and National Education Policy 2020.

With a strong focus on science and technology, the university supports advanced research in areas like artificial intelligence, quantum computing, IoT, environmental science, tribal studies, and sustainable development. It also encourages student-centric initiatives, cultural diversity, and community outreach through programs like NSS, Ek Bharat Shreshtha Bharat, and Skill India.

Guru Ghasidas Vishwavidyalaya continues to play a pivotal role in shaping the academic and professional future of thousands of students, while also contributing meaningfully to the nation's growth in knowledge and innovation.

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