Chapter 5
Edge-Driven Digital-Twin Framework for Real-Time, Privacy-Preserving Adaptive Robotic Tele-Rehabilitation in Home IoMT Environments

T. Grace Shalini
https://orcid.org/0000-0002-0016-3702
S.R.M. Institute of Science and Technology, India

P. Bhavesh
https://orcid.org/0009-0003-1327-9020
S.R.M. Institute of Science and Technology, India

S. S. Krishikaa Mathi Bharathi
https://orcid.org/0009-0002-4079-4864
S.R.M. Institute of Science and Technology, India

Nayantra Ramakrishnan
S.R.M. Institute of Science and Technology, India

ABSTRACT

As populations age and remote care demand grows, tele-rehabilitation must evolve beyond rigid, cloud-heavy models. We propose an edge-driven digital twin framework integrating wearable robotic exoskeletons, home IoMT sensors, and edge compute

DOI: 10.4018/979-8-3373-5447-7.ch005

nodes to create real-time, privacy-preserving rehabilitation. Patient-specific musculoskeletal twins are continuously updated via multimodal sensor fusion, while adaptive algorithms—optimized through federated learning—personalize therapy without transmitting raw data. A lightweight middleware ensures sub-100 ms response, GDPR/HIPAA compliance, and seamless integration with clinician dashboards. In a pilot study on post-stroke gait rehabilitation, the framework improved recovery speed by up to 30% and reduced data exposure risk by 80%, highlighting its potential to transform intelligent, patient-centric home care.

INTRODUCTION

Physical recovery and quality of life in patients who have neurological events, musculoskeletal injuries, or chronic degenerative diseases require rehabilitation. With increasing global populations, the number of persons aged 60 years and above is projected to increase to 22% by 2050, thus, creating a surge in demand on the intensive long period of rehabilitation services. Classical models of rehabilitation assume face-to-face treatment at the hospitals or specialized facilities, where certified therapists can lead the patients through a series of physical activities, physical tests, and trial-and-error procedure manipulation. These face-to-face modalities are costly in controlled environments, geographically limited and unavailable to patients in distant locations or with limited mobility. Access and continuity discrepancies are further increased by transportation obstacles, time constraints, and trainee clinician shortages, (Méndez et al., 2024).

In order to overcome these obstacles, tele-rehabilitation has come out as an option, allowing therapy to extend beyond the four four walls of the clinic through digital forms of communication. Initial systems used basic video conferencing and frozen exercise databases that allowed remote consultations but provided limited customization and no real time feedback. The methods of progress monitoring relied on self-reported data given by patients and check-ins by the clinician, thus giving inconsistent engagement and clinical results. The COVID-19 pandemic led to a rapid shift to tele-rehabilitation, which has proven its ability to sustain continuity of care in the conditions of lockdown: one multicenter study found a 78% rise in patient uptake and a similar functional improvement over in-person therapy, despite the impediments of infrastructure and digital illiteracy, (Johnson et al., 2023a; Garcia et al., 2024).

In the last ten years, the development of wearable sensors, robotics and distributed computing has spurred the transformation of tele-rehabilitation into data-driven, intelligent systems. High-fidelity kinematic and physiological data are now measured using inertial measurement units (IMUs), force and EMG electrodes, bio-impedance