01. Hybrid TCN-BiLSTM Framework for Forecasting Telemedicine Utilization Using Multivariate Digital Health Indicators in India

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ABSTRACT

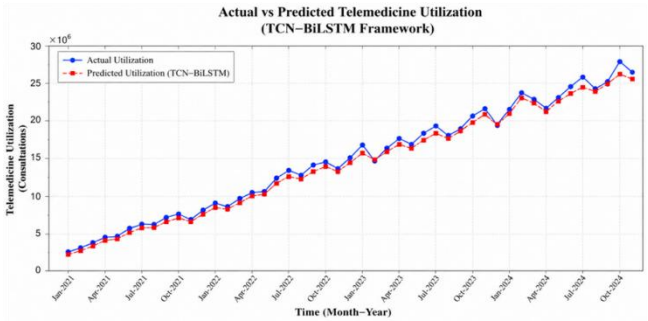
Background: Telemedicine has emerged as an important digital healthcare delivery mechanism for improving healthcare accessibility across geographically diverse regions. Despite the rapid expansion of telemedicine services in India, substantial disparities associated with digital infrastructure, literacy, internet accessibility, urbanization, and healthcare availability continue to influence telemedicine utilization across states and union territories. Conventional statistical and machine learning approaches frequently experience limitations in learning complex temporal healthcare utilization patterns and long-range sequential dependencies within multivariate telemedicine datasets. Therefore, this study developed a hybrid Temporal Convolutional Network-Bidirectional Long Short-Term Memory (TCN-BiLSTM) deep learning framework for forecasting telemedicine utilization using multivariate digital health indicators across India.

Methods: Telemedicine utilization statistics and multivariate digital health indicators were collected from publicly available national repositories including the eSanjeevani telemedicine platform, National Family Health Survey (NFHS-5), Telecom Regulatory Authority of India (TRAI), Census of India publications, and Ministry of Health and Family Welfare databases. The dataset included records from 28 Indian states and 8 union territories between 2020 and 2024. Data preprocessing involved missing value imputation, interpolation, Min-Max normalization, and sequential time-series generation using a sliding window approach. The proposed hybrid framework integrated Temporal Convolutional Network layers for temporal feature extraction and Bidirectional Long Short-Term Memory layers for bidirectional sequential dependency learning. Model performance was evaluated using Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), and Coefficient of Determination (R2).

Results: The findings demonstrated substantial nationwide growth in telemedicine utilization following the expansion of digital healthcare services in India. Significant interstate disparities in telemedicine adoption were identified, particularly among regions with variations in digital infrastructure, literacy, urbanization, and healthcare accessibility. The proposed TCN-BiLSTM framework achieved effective forecasting performance with an RMSE of 0.071, MAE of 0.054, MAPE of 4.38%, and R2 value of 98.9%. The predicted utilization trends closely aligned with actual telemedicine consultation patterns, indicating stable temporal dependency learning and improved forecasting capability.

Conclusion: The proposed hybrid TCN-BiLSTM framework effectively forecasted telemedicine utilization using multivariate digital health indicators and sequential healthcare data. The findings highlighted the influence of digital infrastructure and socioeconomic readiness on telemedicine adoption across Indian states. The developed framework provides a data-driven approach for healthcare planning, telemedicine resource allocation, and future digital healthcare demand estimation within large-scale healthcare systems.

Key Words: Telemedicine; Digital Health; Deep Learning; Temporal Convolutional Network; Long Short-Term Memory



Actual and Predicted Telemedicine Utilization Trends

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