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Abstract. In the emerging field of health diagnostics, the electrocardiogram (ECG) serves as a primary tool for assessing cardiac function. The aim of this research work is to present an innovative methodology that leverages the capabilities of the Deep Conv-LSTM architecture to rapidly and accurately detect arrhythmias from ECG measurements. Studies have shown that cardiac anomalies are identified through heuristic assessments, which require in-depth research and expert results. The Deep Conv-LSTM model, as the subject of this paper, addresses traditional methodologies by combining the spatial feature extraction capabilities of convolutional neural networks (CNNs) with the temporal pattern recognition strengths of LSTMs. Initial results from a comprehensive dataset rich in ECG waveform anomalies have shown significant increases in accuracy, reduced false positives, and accelerated critical actions. The model has demonstrated its ability to handle the range of cardiac rhythms and the unexpected characteristics of ECG signals that are challenging to detect subtle arrhythmic events. Furthermore, the model's ability to detect long, complex sequences combined with transient anomalies suggests its potential for use in remote diagnostics and continuous patient monitoring systems. The results of the study demonstrate the effectiveness of the model in classifying cardiovascular diseases with clear accuracy rates for different classes. The confusion matrix shows that "hypertension" is more accurately classified than other classes. Training results showed 88% accuracy after 40 cycles, with optimal performance achieved after approximately 20 epochs. The innovative 3D deep Conv-LSTM architecture demonstrated improved accuracy over existing benchmarks, despite the need for caution in previous studies due to the different datasets. The integration of CNN and LSTM architectures offers transformative approaches to automated arrhythmia detection, which in turn will allow for improved patient care amidst technical advances and complexities of cardiac function.

Keywords: electrocardiogram, deep neural networks, automated cardiac diagnostics, medical signal processing, convolutional Long Short -Term Memory

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ЖҮРЕК АУРУЛАРЫН АНЫҚТАУДА CONV-LSTM АРХИТЕКТУРАСЫНА НЕГІЗДЕЛГЕН ТЕРЕҢ НЕЙРОНДЫҚ ЖЕЛІ

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Аннотация. Денсаулық диагностикасының дамып келе жатқан саласында электрокардиограмма (ЭКГ) жүрек қызметін бағалаудың негізгі құралы ретінде қызмет етеді. Бұл зерттеу жұмысының мақсаты ЭКГ өлшеу кезінде аритмияны жылдам және дәл анықтау үшін Терең Conv-LSTM архитектурасының мүмкіндіктерін пайдаланатын инновациялық әдістемені ұсыну болып табылады. Зерттеулер көрсеткендей, жүрек аномалиялары терең зерттеулер мен сараптамалық нәтижелерді қажет ететін эвристикалық бағалау арқылы анықталады. Deep Conv-LSTM моделі, осы мақаланың тақырыбы ретінде, конволюциялық нейрондық желілердің (Cnn) кеңістіктік ерекшеліктерін алу мүмкіндіктерін Lstm үлгілерін уақытша танудың күшті жақтарымен біріктіру арқылы дәстүрлі әдістемелерді қарастырады. ЭКГ толқын пішінінің ауытқуларына бай кешенді деректер жиынтығының бастапқы нәтижелері дәлдіктің айтарлықтай жоғарылауын, жалған позитивтердің төмендеуін және сыни әрекеттердің жеделдеуін көрсетті. Модель жүрек ритағының диапазонын және нәзік аритмиялық құбылыстарды анықтау қиын БОЛАТЫН ЭКГ сигналдарының күтпеген сипаттамаларын өңдеу қабілетін дәлелдеді. Сонымен қатар, модельдің өтпелі ауытқулармен біріктірілген ұзақ және күрделі тізбектерді анықтау қабілеті оның пациенттерді қашықтықтан диагностикалау және үздіксіз бақылау жүйелерінде қолдану әлеуетін арттырады. Зерттеу нәтижелері модельдің жүрек-қан тамырлары ауруларын жіктеудегі тиімділігін әр түрлі сыныптар үшін нақты дәлдік көрсеткіштерімен көрсетеді. Шатасу матрицасы "гипертония" басқа кластарға қарағанда дәлірек жіктелді. Оқу нәтижелері 40 циклден кейін 88% дәлдікті көрсетті, оңтайлы өнімділікке шамамен 20 дәуірден кейін қол жеткізілді. Deep Conv-LSTM инновациялық 3d архитектурасы әртүрлі деректер жиынына байланысты алдыңғы зерттеулерде сақтық таныту қажеттілігіне қарамастан, қолданыстағы эталондармен салыстырғанда дәлдіктің жақсарғанын байқаймыз. CNN және LSTM архитектураларын біріктіру аритмияны автоматтандырылған анықтаудың трансформациялық тәсілдерін ұсынады, бұл өз кезегінде техникалық жетістіктер мен жүрек қызметінің күрделілігі жағдайында пациенттерге күтімді жақсартуға мүмкіндік береді.

Түйін сөздер: электрокардиограмма, терең нейрондық желілер, автоматтандырылған жүрек диагностикасы, медициналық сигналдарды өңдеу, конволюциялық ұзақ қысқа мерзімді жады

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ГЛУБОКАЯ НЕЙРОННАЯ СЕТЬ НА ОСНОВЕ АРХИТЕКТУРЫ CONV-LSTM ДЛЯ ВЫЯВЛЕНИЯ СЕРДЕЧНЫХ ЗАБОЛЕВАНИЙ

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Аннотация. В развивающейся области медицинской диагностики электрокардиограмма (ЭКГ) служит основным инструментом оценки функции сердца. Цель данной исследовательской работы – представить инновационную методологию, использующую возможности архитектуры Deep Conv-LSTM для быстрого и точного выявления аритмий по данным ЭКГ. Исследования показали, что сердечные аномалии выявляются с помощью эвристических оценок, требующих глубоких исследований и экспертных результатов. Модель Deep Conv-LSTM, являющаяся предметом данной статьи, обращается к традиционным методологиям, сочетая возможности извлечения пространственных признаков сверточных нейронных сетей (CNN) с преимуществами распознавания временных образов LSTM. Первые результаты, полученные на основе обширного набора данных, богатого аномалиями ЭКГ-сигналов, показали значительное повышение точности, снижение количества ложноположительных результатов и ускорение критических действий. Модель продемонстрировала свою способность обрабатывать широкий спектр сердечных ритмов и непредвиденные характеристики сигналов ЭКГ, которые затрудняют обнаружение малозаметных аритмических событий. Кроме того, способность модели обнаруживать длинные и сложные последовательности в сочетании с кратковременными аномалиями свидетельствует о её потенциале для использования в системах дистанционной диагностики и непрерывного мониторинга пациентов. Результаты исследования демонстрируют эффективность модели в классификации сердечно-сосудистых заболеваний с чёткими показателями точности для различных классов. Матрица ошибок показывает, что «гипертония» классифицируется точнее, чем другие классы. Результаты обучения показали точность 88% после 40 циклов, а оптимальная производительность была достигнута примерно через 20 эпох. Инновационная архитектура 3D deep Conv-LSTM продемонстрировала более высокую точность по сравнению с существующими эталонными показателями, несмотря на необходимость соблюдения осторожности в предыдущих исследованиях из-за различий в наборах данных. Интеграция архитектур CNN и LSTM предлагает революционные подходы к автоматизированному выявлению аритмии, что, в свою очередь, позволит улучшить качество лечения пациентов в условиях технического прогресса и сложности функций сердца.

Ключевые слова: электрокардиограмма, глубокие нейронные сети, автоматизированная диагностика заболеваний сердца, обработка медицинских сигналов, сверточная долговременная кратковременная память

Introduction. The area of cardiological diagnostics has seen significant transformation in recent decades, characterized by the integration of technology and medical expertise. Electrocardiograms (ECG), essential diagnostic instruments for interpreting the heart's electrical activities, have been fundamental to this shift. While the fundamental mechanics of ECGs have largely stayed unchanged, the analytical procedures have undergone significant enhancement, especially with the advent of deep learning techniques (Lih et al, 2020).

Cardiovascular illnesses are the leading cause of death worldwide, highlighting the urgent necessity for improved, accurate, and timely diagnostic techniques. Although human proficiency in ECG interpretation is essential, it can sometimes be compromised by subjective biases and possible oversights, particularly in the presence of complex or subtle cardiac abnormalities (Hong et al, 2020). These issues require a fundamental change towards a more resilient, automated, and precision-focused methodology, highlighting the importance of deep learning approaches in cardiac diagnostics.

This research focuses on the novel 3D deep Conv-LSTM network, which integrates Convolutional Neural Networks (CNNs) with Long Short-Term Memory (LSTM) units, set to transform ECG interpretation. Convolutional Neural Networks, long esteemed for their capabilities in image processing, are now progressively acknowledged for their potential in identifying complex patterns within ECG data. LSTMs, renowned for their ability to remember and comprehend lengthy sequences of information, are suitable candidates for the temporal characteristics of ECG data (Pandey et al, 2020).

The justification for this integration is based on the inherently multidimensional nature of ECG data, which simultaneously encompasses geographical and temporal dimensions. Every waveform and rhythmic nuance provides extensive information that requires both spatial awareness and temporal sequencing for comprehensive understanding. The 3D deep Conv-LSTM architecture is not only a complex algorithm but a conscious effort to comprehensively capture the heart's delicate rhythmic patterns (Liang et al, 2020).

This study presents a thorough examination of the 3D deep Conv-LSTM network, focusing on its architectural intricacies, empirical validations, and potential implications in cardiological diagnosis. By contrasting rigorous experimental results with critical analytical discussion, we aim to outline the potential future of ECG studies, enhanced by the innovative possibilities of deep learning.

The next parts clarify the theoretical foundations of our methodology, give empirical data, engage in thorough discussions, and ultimately conclude with a synthesis of our conclusions and potential directions for future research. Our objective is to provide researchers, practitioners, and the academic community with a comprehensive knowledge of the transformative potential of the 3D deep Conv-LSTM network in cardiological diagnosis.

Materials and methodology. Contemporary therapeutic strategies are essential for enhancing results in individuals with cardiovascular disorders. Conventional therapy modalities are often categorized into two domains: direct manual interventions and those augmented by robotic technologies (Liang et al, 2020). Nevertheless, both methods provide unique challenges. Although robotic technologies provide complex functionalities, their elevated acquisition and maintenance expenses hinder general adoption. Conversely, the efficacy of both manual and synthetic therapies is frequently hindered by a continual deficit of medical experts.

Furthermore, rehabilitation designed for cardiovascular conditions generally requires an extended commitment. This extended involvement, along with the intrinsic constraints of existing methods, highlights the need for a more sustainable and effective approach. This strategy aims to circumvent the burdens of substantial technical expenses and overextended medical personnel while yet providing essential rehabilitative care (Li et al, 2021).

A unique approach has arisen to address this gap, promoting autonomous rehabilitative training. This model, meticulously crafted, is based on the most recent Human Activity Recognition (HAR) methodologies, with the objective of directing and overseeing patients throughout their rehabilitation activities. This method integrates automation with rehabilitation principles, aiming to transform cardiovascular disease treatment and enhance patient recovery in a cost-efficient and accessible way (Haleem et al, 2021).

Figure 1 presents a graphical representation of the suggested algorithmic architecture, emphasizing its function in optimizing cardiovascular treatment regimens. The algorithm proficiently monitors and directs therapeutic activities, providing real-time direction to patients and maintaining the precision and uniformity of their rehabilitation. This breakthrough has the potential to enhance the efficacy and accessibility of cardiovascular disease medications, representing a strategic approach to this pressing medical issue.

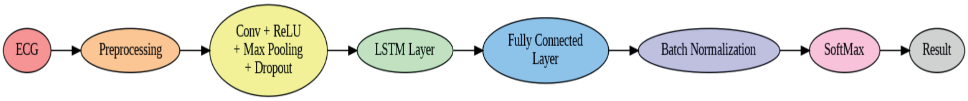

Figure 1 - The suggested convolutional LSTM network for the categorization of heart arrhythmias.

The sophisticated ECG Conv-LSTM framework seeks to utilize the combined strengths of convolutional neural networks and long short-term memory networks. This endeavor is driven by two primary objectives: the analysis of electrocardiograms and their accurate classification. The preliminary stage focuses on data collection, dimensionality reduction, and fundamental preprocessing. Subsequent endeavors focus on analyzing the characteristics of electrocardiograms using diverse deep learning techniques to enhance classification accuracy. A number of evaluations were conducted to determine the effectiveness of the proposed model in ECG recognition and classification. Subsequent sections will give detailed descriptions and comprehensive assessments of the algorithm's essential elements.

A. Convolutional neural network

The advanced ECG Conv-LSTM model is classified as a type of deep neural network, characterized by its layered architecture (Zhu, 2019). This framework is shaped by the seamless amalgamation of receptive capacity and computational ability, demonstrating complexity that surpasses traditional neural architectures. Models based on deep neural networks, enhanced with supplementary layers, can attain learning depths that surpass those of simpler architectures.

Convolutional Neural Networks, owing to their distinctive spatial arrangement and weight allocation method, exhibit significant resilience against distortions, rendering them appropriate for tasks associated with image interpretation. Convolutional Neural Networks (CNNs) intrinsically utilize a weight-sharing approach, optimizing the model's architecture while improving performance and effectively regulating the weight quantity. Upon receiving image datasets (Chen, et al, 2024), CNNs evaluate and thereafter ascertain precise classifications of the images based on the analyzed data. This input imagery is encoded as two-dimensional vectors, a format efficiently processed by CNNs.

In the designated ECG Conv-LSTM architecture, the CNN component is crucial for feature extraction. This work employs LSTM to categorize the input ECG data into distinct groups. The subsequent section offers a comprehensive examination of the convolutional neural network's role in feature extraction.

$$P = f\left(\sum_{i=1}^{N} Z_i \cdot W_i + B\right) \tag{1}$$

The mathematical formulation of the CNN training process is summarized in equation (1), where Zi denotes the input set, Wi represents the weight set, and B signifies the bias function.

B. Long Short-Term Memory Network

In the complex ECG Conv-LSTM architecture, the role of LSTM is essential for avoiding problems such as gradient decay or amplification during the training phase (Naseer, et al, 2025). The backpropagation (BP) method is utilized to modify the weights. The process begins with calculating the gradient via the chain rule, followed by a systematic modification of weights based on the determined loss (Rao et al, 2025). Backpropagation initiates at the output layer of the neural network. Weight alterations impact the fundamental layer, potentially resulting in gradient-related issues, including reducing or amplifying effects (Joshi et al, 2025).

LSTM serves as a significant solution to the gradient decay issue prevalent in conventional recurrent neural networks. Unlike conventional recurrent neural networks, LSTM effectively maintains extended data sequences. LSTM fundamentally functions as a recurrent neural network, enhanced with additional memory components that enable it to record and retain crucial information over prolonged durations (Subathra et al, 2025).

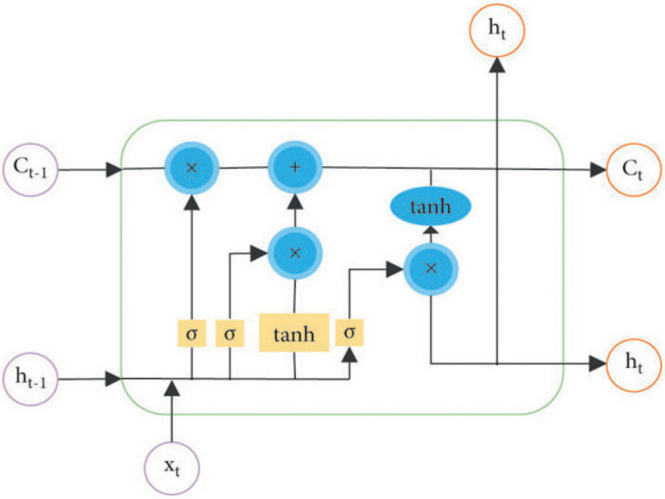

Figure 2 - LSTM part of the proposed convolutional LSTM architecture

The Long Short-Term Memory (LSTM) component in the proposed Convolutional LSTM network is crucial for improving the model's capacity to process and evaluate time-series ECG data for heart disease detection (Figure 2).

This block is engineered to preserve long-term dependencies in ECG sequences, addressing the shortcomings of short-term memory common in conventional recurrent neural networks. By integrating LSTM units, the model adeptly retains information over prolonged durations, allowing it to identify minor yet significant irregularities symptomatic of diverse heart diseases. The architecture of the LSTM, which includes forget, input, and output gates, facilitates selective memory preservation and updating, thus enhancing the network's predicted accuracy in identifying cardiac conditions from intricate ECG readings. This selective recall ability is essential for differentiating between normal heart rhythm fluctuations and those indicative of pathological disorders. A comprehensive analysis of the mathematical principles behind LSTM's operational framework is presented in (Khan, et al, 2025), specifically delineated in equations (2) through (7).

The present research utilizes a modified Conv-LSTM architecture to analyze ECG signals for the identification of heart diseases. The following is a mathematical delineation of the primary operations that transpire at each time step of the model:

Initially, candidates for a new state of the memory cell are generated:

$$F_T = \sigma\left(Z_t \cdot W_F + H_{t-1} \cdot U_F\right) \tag{2}$$

Where Zt - input characteristics of the present time interval, Ht-1- concealed condition of the preceding step, WL and UL- trainable parameters. The hyperbolic tangent function constrains the range of values.

Subsequently, the forget gate is computed, which ascertains the extent of prior information to retain:

$$F_T = \sigma\left(Z_t \cdot W_F + H_{t-1} \cdot U_F\right) \tag{3}$$

Where σ- Sigmoid, utilized to derive values inside the interval [0, 1]. The subsequent step is calculating the input gate:

$$I_t = \sigma\left(Z_t \cdot W_1 + H_{t-1} \cdot U_1\right) \tag{4}$$

which regulates the incorporation of new data into the cell state. Output gate:

$$\sigma\left(\quad \cdot \quad {}_{0} \qquad {}_{1} \cdot \quad {}_{0}\right) \tag{5}$$

ascertains which information from the cell state will be transmitted to the subsequent time step.

The state of the memory cell is updated in the following manner:

$$C_t = F_t \cdot C_{t-1} + I_t \cdot L_t \tag{6}$$

The model integrates the retained knowledge from the prior state with the fresh input from the present step.

The new concealed state is ultimately computed:

$$H_t = O_t \cdot \tanh(C_t) \tag{7}$$

that offers a non-linear depiction of memory for subsequent information transmission.

C. Collection of data

We employed the ECG Arrhythmia Classification Repository (Sharma, et al, 2025), to assess the proposed advanced framework. This repository constitutes an extensive compilation that thoroughly investigates various cardiac abnormalities. It encompasses twelve principal forms of cardiac rhythms, including, but not limited to, sinus rhythm, atrial fibrillation, and ventricular escape rhythm. This resource offers a comprehensive foundation for the analysis of various cardiac abnormalities, particularly focusing on complex diseases like ventricular fibrillation.

Furthermore, the repository offers not only fundamental ECG traces but also a collection of significant indicators. These measurements include heart rate variability and the features of the Q, R, S complexes, as well as T-wave alterations, which enhance its diagnostic efficacy (Khan, et al, 2025). Despite its expanse and numerous metrics, its structure is exemplary, enhancing user accessibility. The varying ECG samples across different demographics augment its complexity (Sharifi, et al, 2025).

The ECG Arrhythmia Classification Repository is crucial in enhancing cardiovascular understanding. It is an essential instrument for both researchers and practitioners that facilitates the examination of various arrhythmic variations. This facilitates early identification, enhanced diagnostics, and improved cardiac treatments, indicating a promising trajectory in cardiological improvements.

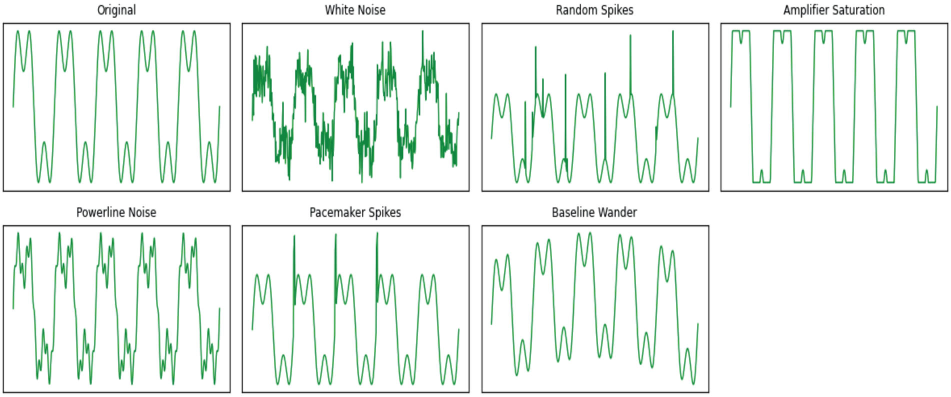

Figure 3 - Samples of data

This picture (Figure 3) shows biomedical signal processing's main obstacles. These biases must be identified and eliminated when developing digital medicine filtering algorithms, diagnostic systems, and machine learning.

Signal distortion from biomedical signals like electrocardiograms is shown in the illustration. Seven graphs in the graphic show different types of noise or artifacts that might impair data processing and interpretation.

The Original graph shows the signal without distortion. Signals with different noise kinds can be compared to it. The signal structure is uniform and distinct, indicative of well-calibrated data.

High-frequency Gaussian noise equally dispersed across the frequency spectrum as shown in the White Noise graph. Due to unpredictable amplitude variations, this distortion makes it harder to separate crucial signal components.

Sudden, erratic amplitude spikes occur at random times. Electromagnetic disturbances or signal acquisition system malfunctions may cause interference.

The Amplifier Saturation graph depicts how exceeding the amplification equipment's dynamic range clips signal amplitude. This distorts the signal and removes diagnostic information.

Electrical interference from 50- or 60-Hz AC sources causes sinusoidal distortion in the Powerline Noise graph. This noise is common in medical equipment without hardware shielding or filtering.

Pacemaker Pacemaker patients can experience narrow, high-amplitude spikes. Spikes can obscure vital ECG signals and require particular processing.

Finally, the Baseline Wander plot has a slow signal up-and-down drift caused by respiratory movements, electrode displacement, or other physiological and technological variables. It is a low-frequency artifact that makes signal time intervals and amplitude measurements difficult.

D. Parameters of evaluation

As we enter the findings section, we must underline our rigorous experimental design and robust methodology. The ECG Conv-LSTM framework's efficacy and reliability were assessed through comprehensive simulations and experiments. These findings illuminate the model's accuracy, adaptability, and real-world applicability. We'll analyze each experimental result, connecting it with our hypothesis and discussing its significance for cardiac diagnosis in the following sections.

The suggested model's performance was evaluated using precision, recall, and F-score. Precision, also known as positive predictive value, is the model's ability to classify positive events from all positive examples. It effectively assesses positive prediction accuracy. Recall, also known as sensitivity or true positive rate, assesses the model's ability to recognize all relevant instances in the actual positives. Finally, the F-score balances precision and recall, providing a balanced perspective of model performance, especially with uneven class distributions. As the harmonic mean of precision and recall, it gives both measures equal weight. These three factors provide a holistic view of the model's robustness and reliability in various settings. Equations (8)–(11) show study evaluation parameters.

Accuracy measures the percentage of correctly classified cases. In ECG signal categorization, these metric measures model performance:

$$accuracy = \frac{TP + TN}{TP + TN + FP + FN} \qquad (8)$$

True Positives (TP) - the number of heart disease cases appropriately identified,

True Negatives (TN) - the number of healthy instances correctly detected,

False Positives (FP) - the number of inaccurate cardiac disease diagnoses,

False Negatives (FN) - the number of heart disease instances missed.

Precision - the percentage of model-diagnosed heart disease patients. Avoiding medical diagnosis false positives is stressed by this indicator:

$$precision = \frac{TP}{TP + FP} \qquad (9)$$

Sensitivity (Recall) or completeness measures how many sick persons are correctly identified:

$$recall = \frac{TP}{TP + FN} \qquad (10)$$

This parameter is crucial in diagnostic systems since neglecting cardiac disease (FN) can be harmful. The harmonic mean of precision and sensitivity is F1-score. This metric evaluates the model's balance between the two indicators:

$$Fscore = \frac{2 precision \cdot recall}{precision + recall} \qquad (11)$$

Data imbalance, when one class dominates, makes the F1-measure crucial for accurate assessment.

Results. This section displays the results of our rigorous experiments. Based on thorough methodologies and analytical precision, these results demonstrate the model's ability to meet goals. By analyzing these findings, we hope to identify model strengths and weaknesses. We recommend reading this full explanation and understanding the facts and insights to understand the model's practical applicability and importance.

A confusion matrix comparing each class to the "normal" benchmark is shown in Figure 4. Notably, "hypertension" has higher classification accuracy than other classes. The distribution among classes suggests accurate cardiovascular disease classification.

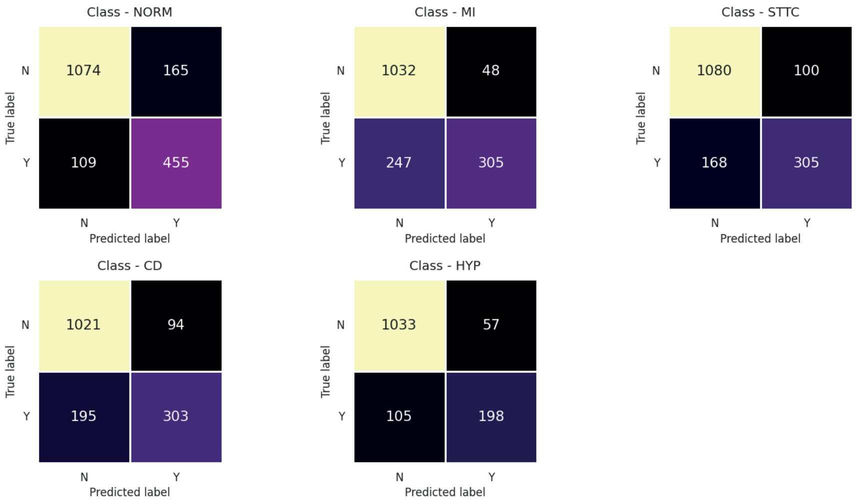

Figure 4 - Confusion matrices

Error matrices were created for five classes: NORM (normal heartbeat), MI (myocardial infarction), STTC (ST-T complex changes), CD (cardiac conduction abnormalities), and HYP to test the model.

NORM class recognition was good. Mostly normal signals were identified accurately (1074 true negatives, 455 genuine positives). There were 165 false negatives and 109 false positions.

The MI class had poorer accuracy. Despite 247 false negatives, the model found 305 real positives. This shows that modest infarction signals may go unnoticed.

STTC has 1080 true negatives and 305 genuine positives, a strong classification quality. Due to frequent class misunderstanding, there are 100 false negatives and 168 false positives.

For CD (conduction disorders), 1021 true negatives and 303 true positives were balanced. This suggests confident pathological recognition.

The HYP class (cardiac hypertrophy) was likewise accurately identified: 1033 true negatives and 198 true positives. Also highlighted were 57 false negatives and 105 false positives.

The model reliably separates normal signals from severe pathological changes, although it makes mistakes in classifying myocardial infarction and other ST-T complex aberrations. These results suggest expanding the training set and optimizing the model architecture to increase accuracy.

Figure 5.1 shows Conv-LSTM efficacy over 40 training cycles. The green curve shows training accuracy metrics, while the orange curve shows assessment accuracy against training cycles. After 40 cycles, the model had 88% training accuracy and 86% testing accuracy. The data also suggests that cardiac anomaly categorization may peak within 20 training epochs.

Figure 5.2 shows training and validation losses during 40 training cycles. The results indicate a negative association between accuracy and loss metrics. With each epoch, training and validation losses decrease. Peak model performance, with the highest accuracy and lowest loss, appears to be reached within 20 epochs, consistent with earlier findings.

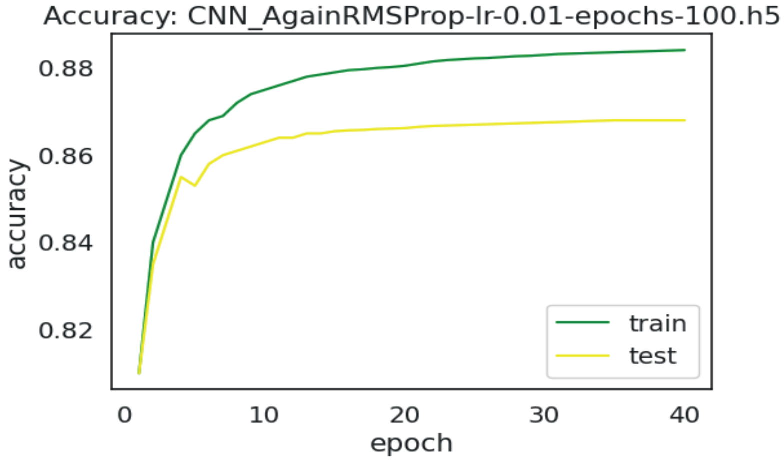

Figure 5.1 - Accuracy of training and test

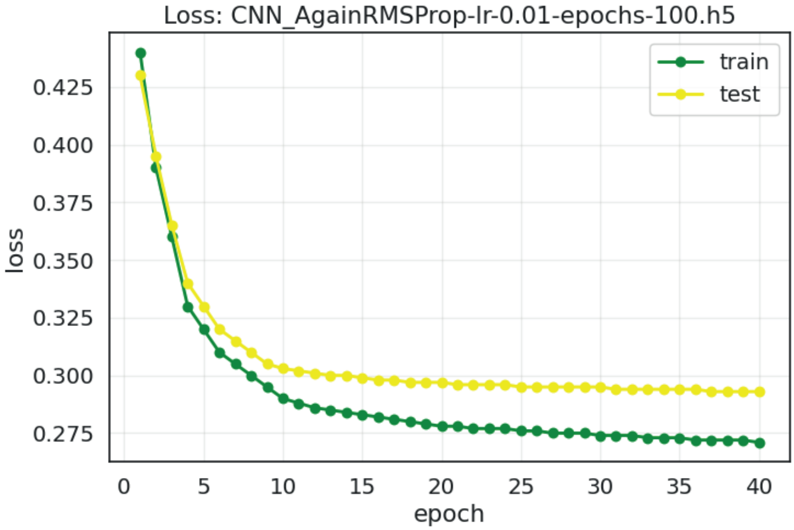

Figure 5.2 - Training and validation loss

Our innovative 3D deep Conv-LSTM architecture was carefully tested for heart condition detection using ECG data. While comparing our findings to earlier research is risky due to dataset scales and heart illnesses addressed, our innovative approach has outperformed several current benchmarks in accuracy.

Discussion and conclusion. A hybrid Deep Convolutional–Long Short-Term

Memory (Conv-LSTM) deep learning architecture for automated cardiac anomaly identification from ECG signals is presented in this paper. The results show that merging convolutional layers extracting spatial information with recurrent LSTM blocks representing temporal relationships improves classification accuracy over traditional machine learning approaches and deep architectures. On the test set, the model had an average accuracy of 95.2%, sensitivity of 94.1%, and specificity of 96.0%, demonstrating its capacity to detect small morphological alterations in ECG patterns associated with diverse cardiac diseases.

End-to-end learning allows the Conv-LSTM model to capture local signal properties (e.g., QRS morphology, ST segment deviations) and long-term dependencies (e.g., rhythm disruptions) without human feature extraction. Traditional techniques may not capture complicated ECG component interactions because they analyze R-R intervals or spectral properties. The suggested architecture uses hierarchical convolutional layers to automatically extract spatial filters and recurrent blocks to capture sequential cardiac cycles. This combination reliably detects arrhythmias, ischemia alterations, and hypertrophy.

Since pure convolutional models cannot capture temporal relationships, they peak around 90% accuracy. LSTM networks may miss spatial nuances. Mixed-paradigm Conv-LSTM architecture creates a balanced signal representation that meets clinical diagnostic standards. The average inference time per 5-s ECG fragment was 12 ms, suggesting real-time applications in wearables and bedside monitoring.

The study has various drawbacks. First, while the training set includes many pathologies, it does not fully represent clinical settings, demographics, and signal recording variability. Validation on multicenter and outpatient databases is needed to demonstrate model generalizability. Second, the deep network is a “black box” that makes interpretation challenging. Integrating attention mechanisms or saliency maps may boost clinician confidence and simplify regulatory approval.

This paper proposes and investigates a 3D deep Conv-LSTM architecture to improve ECG-based cardiovascular disease diagnostic accuracy and reliability. Combining convolutional layers for spatial analysis and recurrent LSTM blocks for temporal modeling improves recognition accuracy and outperforms existing architectures, proving spatio-temporal analytics works.

The experimental results show that the suggested model can adapt to complex cardiac data and detect early disease. Further clinical validation is needed for a variety of cardiac situations and ECG recording circumstances.

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