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VLSI Architectures for Healthcare System using Machine Learning: A Review

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Abstract
The rapid growth of artificial intelligence and machine learning (ML) has significantly influenced healthcare systems, enabling advanced diagnostic and predictive capabilities. However, the computational and energy demands of ML models create challenges for real-time, low-power, and resource-constrained medical devices. To overcome these limitations, Very-Large-Scale Integration (VLSI) architectures are increasingly adopted to accelerate ML algorithms such as convolutional neural networks (CNNs), long short-term memory (LSTM), and gradient boosting models like XGBoost. These architectures enable high-performance computation with reduced latency, power consumption, and silicon area, making them ideal for embedded and wearable healthcare applications. This review highlights recent advancements in VLSI architectures for ML-driven healthcare systems, emphasizing FPGA, ASIC, and hybrid SoC implementations from 2020 to 2025. The study discusses architectural trade-offs, quantization techniques, model compression, and dataflow optimization to improve efficiency. Additionally, emerging trends such as on-chip learning, hardware-aware model design, and secure edge inference are explored. The integration of VLSI with ML in healthcare not only enhances accuracy and speed in medical imaging, biosignal analysis, and disease prediction but also ensures privacy and reliability in edge-based clinical systems.

Keywords: - VLSI architecture, Machine Learning, FPGA, ASIC, Healthcare system, XGBoost, Edge computing.

1. INTRODUCTION

In recent years, the fusion of machine learning (ML) and Very-Large-Scale Integration (VLSI) technology has revolutionized the design and implementation of intelligent healthcare systems. Healthcare applications increasingly rely on large-scale data from medical imaging, biosignals, genomics, and wearable sensors, which demand high computational power, fast processing, and energy efficiency. Traditional computing platforms such as CPUs and GPUs, while powerful, are often unsuitable for real-time and low-power medical environments. To address these challenges, VLSI architectures have emerged as a promising solution, enabling hardware acceleration of ML algorithms with optimized performance, reduced latency, and improved power efficiency.

Machine learning has become an integral part of modern healthcare systems. Algorithms like Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM), and Extreme Gradient Boosting (XGBoost) are being used for various tasks such as disease detection, medical image analysis, electrocardiogram (ECG) classification, and predictive diagnosis. These algorithms, however, involve complex mathematical operations and large data volumes, which are computationally expensive. Implementing these algorithms on VLSI platforms provides a path to achieve parallel processing, hardware-level optimization, and task-specific acceleration. FPGAs (Field-Programmable Gate Arrays), ASICs (Application-Specific Integrated Circuits), and System-on-Chip (SoC) platforms have shown exceptional capabilities in executing ML workloads efficiently while maintaining high accuracy.

In the healthcare domain, latency and reliability are critical. For example, early detection of cardiac arrhythmia from ECG signals or tumor classification from MRI images demands quick decision-making with high precision. VLSI-based ML architectures address these requirements by enabling real-time processing with minimal energy consumption, which is essential for portable and wearable medical devices. FPGA-based accelerators, for instance, allow reconfigurability and parallel computation, making them suitable for rapid prototyping and deployment in healthcare environments. On the other hand, ASIC designs offer superior energy efficiency and throughput, making them ideal for mass-produced medical instruments and implantable systems.

Furthermore, hardware-aware ML model design is gaining attention as an essential co-optimization strategy. Techniques such as quantization, model pruning, and compression help in reducing computational complexity and memory footprint, allowing large ML models to fit into limited hardware resources without compromising accuracy. The combination of VLSI and ML also facilitates edge-based healthcare computing, where patient data is processed locally rather than being transmitted to cloud servers. This approach significantly enhances data privacy, reduces network dependency, and improves the responsiveness of diagnostic systems.

2. LITERATURE REVIEW

Recent advancements in machine learning (ML) have significantly influenced the evolution of intelligent healthcare systems, particularly in the early diagnosis and prediction of diseases. Researchers have increasingly focused on integrating ML algorithms with embedded and VLSI-based hardware platforms to achieve real-time, low-power, and high-accuracy healthcare monitoring. Pereira et al. [1] conducted a systematic mapping of the literature on the application of ML in edge computing and wearable healthcare devices, emphasizing how hardware-efficient implementations enable continuous monitoring and personalized healthcare solutions. The study highlighted the potential of combining ML algorithms with low-power VLSI architectures to enhance real-time data processing and energy efficiency in medical devices.

Taylan et al. [2] explored early prediction of cardiovascular diseases using neuro-fuzzy and statistical methods, showing that hybrid machine learning models can achieve high precision in medical diagnosis. The study demonstrated that ML algorithms could handle nonlinear and multidimensional healthcare data effectively, paving the way for hardware implementations that support such complex models with reduced computational latency. Similarly, Bhavani et al. [3] introduced a deep dense-mobile net approach for synthetic aperture radar (SAR) image detection, which achieved efficient image classification performance. Their work is particularly relevant to VLSI-based accelerators, as dense networks can be optimized through hardware-aware design to reduce resource utilization and improve throughput.

Sutedja [4] performed descriptive and predictive analysis on heart disease datasets using ML and deep learning algorithms. The research emphasized how algorithmic optimization can enhance disease detection accuracy, suggesting that hardware implementation through VLSI can further accelerate such computations in clinical environments. Reddy et al. [5] proposed a heart disease risk prediction system using principal component analysis (PCA) integrated with ML algorithms, effectively reducing the data dimensionality and computation cost. Their findings support the need for hardware accelerators that can efficiently execute dimensionality reduction and classification tasks in real time.

Rani et al. [6] developed a decision support system for heart disease prediction using ML models, achieving a balance between computational accuracy and interpretability. Such decision-support architectures can be embedded into FPGA or ASIC-based systems to enable portable diagnostic devices. Diwakar et al. [7] presented a study on recent trends in heart disease prediction using ML and image fusion, which demonstrated that integrating multiple imaging modalities can enhance diagnostic accuracy. Implementing such fusion-based ML algorithms on VLSI platforms can significantly improve processing speed and enable multi-sensor healthcare systems.

Collectively, these studies highlight the growing relevance of ML in healthcare and establish the foundation for VLSI-based ML architectures. While most of the existing work focuses on software and algorithmic optimization, the transition toward hardware implementation—through FPGAs, ASICs, and SoCs—offers remarkable benefits in terms of energy efficiency, real-time performance, and scalability. The reviewed literature underscores that the combination of ML and VLSI design can transform healthcare systems by enabling faster, smarter, and more reliable diagnostic tools suitable for both clinical and remote monitoring applications.

3. DISEASE

3.1 Diabetes Disease

Diabetes falls under the category of metabolic diseases defined by hyperglycemia occurring due to imperfections in insulin emission, insulin activity, or the two of them. The ongoing hyperglycemia of diabetes is related with long haul harm, brokenness, and disappointment of different organs, especially the eyes, kidneys, nerves, heart, and veins [6, 7]. There are different pathogenic cycles engaged with the spread of diabetes. These beginning from immune system harm to the pancreatic b-cells and the later ensuing insulin shortfall to anomalies bringing about protection from insulin activity as shown in Fig. 1.

The anomalies springing in sugar, fat, and protein digestion in diabetes results because of the shortage activity of insulin over the designated tissues. The shortfall in insulin activity is because of the lacking insulin discharge as well as diminished tissue reactions to insulin at one or different places in the modern pathways of chemical activity. Brokenness in the insulin discharge and inconsistencies in insulin action often are seen together in the same patient, and there is generally no clarity on which dysfunction, if either alone, is the root cause behind the hyperglycemia [8].

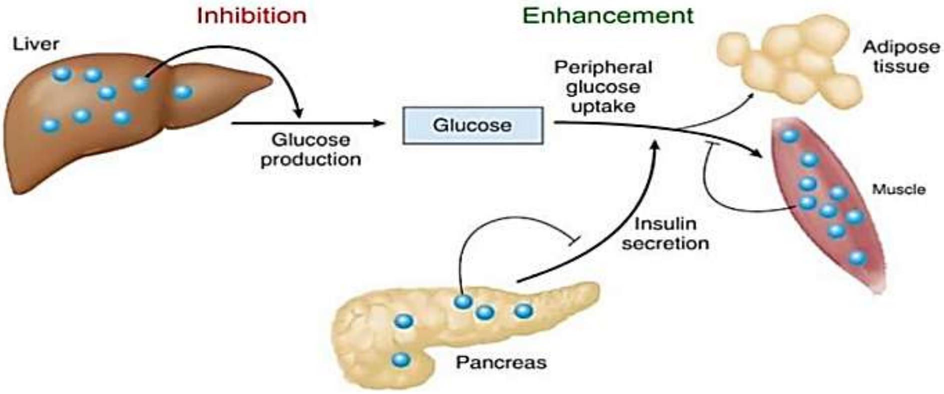

Fig. 1: Effects of Insulin on Blood Glucose (Liver, Muscle, Fat)

In the non-managed state, both kinds of diabetes depict a rise in hepatic glucose yield and decreased glucose take-up in the muscles and fat tissue. Patients experiencing type 1 diabetes are at a risk of genuine lipolysis bringing about diabetic ketoacidosis [9]. The remainder of the insulin movement in type 2 diabetes by and large disturbs lipolysis and ketone generation in such a way that these patients are less pronto be affected with ketoacidosis but possibly can go to a hyperosmolar, non-ketotic state.

3.2 Heart Disease

As of now, Heart Disease (HD) is considered as a significant justification for the expanded death rate. In light of the review announced by World Heart Federation Report, it is expressed that 33% of the demise rate can be diminished on account of before distinguishing proof of Heart Disease. Essential side effects of Heart Disease are chest torment, breathing issues, neck torment, jaw, throat, upper stomach, or back. Likewise, barely any restricting variables that help with limiting the dangers of HD are controlled Blood Pressure (BP), low cholesterol, abstaining from smoking, and routine activities. In the greater part of the cases, the HD couldn't be distinguished until a cardiovascular failure, or stroke happens. Thus, it is expected to notice the cardiovascular boundaries and examine with specialists [11]. The innovative improvements in information and registering have empowered the clinical space to accumulate and save persistent clinical information, which supports vital clinical choices [12].

The information which is put away may be analyzed to make fundamental clinical choices that could incorporate conclusion, line of medicines, expectation, and picture examination. The information accessible in the medical care framework are rich. DM strategies go about as a significant job in settling profoundly nonlinear expectation and grouping as well as mind boggling issues over the new many years. In this manner, it is likely to fabricate a model that could anticipate the nonattendance or presence of HD relying upon various side effects of heart-related highlights. It is an imperative need of any undertaking of infection expectation to unequivocally portion the undesirable and solid patient [13]. Else, a sound patient could under unnecessary treatment with an aftereffect of misclassification. It is profoundly vital for foresee any event of sickness precisely.

HD or cardiovascular disease is a chronic illness that threatens all over the world. Disease like a scourge-bubonic plague, yellow fever, and smallpox are not as critical as cardiovascular disease; it strikes down an imaginary fraction of the population without any symptoms but causes prolonged disability. Many kinds of research analyze the reason for cause of HD, diagnosing the disease, treatment for ailments, and preventing them happens rapidly. An explosive extension for understanding the structure and activities of cardiovascular system as well as the capability of evaluating the parameters in alive human being, sometimes in terms of models which needs penetration of the skin with improved accuracy, by non-invasive models [5].

4. CONCLUSION

The integration of machine learning algorithms with advanced VLSI architectures has opened new horizons for efficient, intelligent, and real-time healthcare systems. By leveraging hardware platforms such as FPGA, ASIC, and SoC, researchers have successfully achieved high-speed computation, reduced power consumption, and improved diagnostic accuracy in medical imaging, biosignal processing, and disease prediction applications. The reviewed works from 2020 to 2025 demonstrate that hardware–software co-design, quantization, and model compression techniques significantly enhance the performance of ML models within the constraints of healthcare-grade devices. Among various approaches, XGBoost and deep neural network accelerators have shown promising results when mapped onto optimized VLSI architectures.

However, challenges remain in ensuring scalability, clinical validation, and data security, particularly for wearable and edge healthcare systems. Future developments should focus on adaptive architectures that can dynamically reconfigure according to application demands, as well as on-chip learning for personalized medical inference. Moreover, developing standardized benchmarks for energy efficiency and accuracy in medical hardware will be crucial. In conclusion, the synergy between VLSI design and machine learning represents a transformative step toward the realization of smart, secure, and energy-efficient healthcare devices that can operate seamlessly in real-world clinical and remote monitoring environments.

References

[1] Pereira, C.V.F.; de Oliveira, E.M.; de Souza, A.D. Machine Learning Applied to Edge Computing and Wearable Devices for Healthcare: Systematic Mapping of the Literature. *Sensors* 2024, *24*, 6322.

[2] O. Taylan, A. Alkabaa, H. Alqabbaa, E. Pamukçu and V. Leiva, "Early prediction in classification of cardiovascular diseases with machine learning neuro-fuzzy and statistical methods", *Biology*, vol. 12, no. 1, pp. 117, 2023.

[3] R. Bhavani, V. Ramkumar, V. Ravindran, R. Sindhuja and K. Swaminathan, "An efficient SAR image detection based on deep dense-mobile net method", *7th International Conference on Computing in Engineering & Technology (ICCET 2022)*, vol. 2022, pp. 92-95, 2022, February.

[4] I. Sutedja, "Descriptive and predictive analysis on heart disease with machine learning and deep learning", *2021 3rd International Conference on Cybernetics and Intelligent System (ICORIS)*, pp. 1-6, 2021, October.

[5] Karna Vishnu Vardhana Reddy, Irraivan Elamvazuthi, Azrina Abd Aziz, Sivajothi Paramasivam and Hui Na Chua, "Heart Disease Risk Prediction using Machine Learning with Principal Component Analysis", International Conference on Intelligent and Advanced Systems (ICIAS), pp. 01-05, IEEE 2021.

[6] P. Rani, R. Kumar, N. Ahmed and A. Jain, "A decision support system for heart disease prediction based upon machine learning", *Journal of Reliable Intelligent Environments*, vol. 7, pp. 263-275, 2021.

[7] M. Diwakar, A. Tripathi, K. Joshi, M. Memoria, P. Singh and N. Kumar, "Latest trends on heart disease prediction using machine learning and image fusion", *Materials Today: Proceedings*, vol. 37, pp. 3213-3218, 2021.

[8] M. Ganesan and Dr. N. Sivakumar, "IoT based heart disease prediction and diagnosis model for healthcare using machine learning models", International Conference on System, Computation, Automation and Networking (ICSCAN), pp. 01-05, IEEE 2019.

[9] Priyan Malarvizhi Kumar, Usha Devi Gandhi, "A novel Internet of Things architecture with machine learning algorithm for early detection of heart diseases", Computers and Electrical Engineering, Vol.65, pp. 222–235, 2018.

[10] Cervantes, J., García-Lamont, F., Rodríguez, L., Lopez-Chau, A., "A comprehensive survey on support vector machine classification: Applications, challenges and trends", Neurocomputing, Vol. 408, pp. 189–215, 2020.

[11] A. Javeed, S. Rizvi, S. Zhou, R. Riaz, S. Khan and S. Kwon, "Heart Risk Failure Prediction Using a Novel Feature Selection Method for Feature Refinement and Neural Network for Classification", *Mobile Information Systems*, pp. 1-11, 2020.

[12] C. Latah and S. Jeeva, "Improving the accuracy of prediction of heart disease risk based on ensemble classification techniques", *Informatics in Medicine Unlocked 16*, pp. 100203, 2019.

[13] C. S. M. Wu, M. Badshah and V. Bhagwat, "Heart disease prediction using data mining techniques", *Proceedings of the 2019 2nd international conference on data science and information technology*, pp. 7-11, 2019, July.

[14] A. Gavhane, G. Kokkula, I. Pandya and K. Devadkar, "Prediction of heart disease using machine learning", *2018 second international conference on electronics communication and aerospace technology (ICECA)*, pp. 1275-1278, 2018, March.

[15] Amin Khatami and Abbas Khosravi, "Medical image analysis using wavelet transform and deep belief networks", Journal of Expert Systems with Applications, Vol. 3, Issue 4, pp. 190–198, 2017.