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ORIGINAL

Cyber-Physical Systems Integration in Healthcare: AI-Enabled Decision Support Systems

Integración de sistemas ciberfísicos en la atención médica: sistemas de apoyo a la toma de decisiones basados en IA

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ABSTRACT

The convergence of Cyber-Physical Systems (CPS) and healthcare is bringing about a transformation in the delivery of patient care by bridging the gap between the digital and physical realms. By utilizing modern technologies, these systems make it possible to make intelligent decisions and gain insights that are driven by data in real time.
Introduction: the complexity of data integration, the mitigation of sophisticated cyber threats, and the guaranteeing of system scalability within a variety of healthcare infrastructures are among the most significant obstacles.
Method: this research presents the Artificial Intelligence-Enabled Intrusion Quantum Predictive Detection System (AI-IQPDS), an innovative approach that is intended to improve the operational reliability of healthcare CPS, as well as the security and predictive analytics capabilities of the system. AI-IQPDS combine quantum computing and machine learning to provide accurate intrusion detection and predictive decision assistance. Intelligent patient monitoring systems powered by AI can optimize hospital resource management, transmit data securely between connected devices, and detect emergencies early working.
Results: simulation results show that the system outperforms modern techniques in terms of precision of detection, speed of processing, and reduction of false-positives. The results of this research demonstrate the revolutionary possibilities of using CPS driven by AI in healthcare.
Conclusions: healthcare ecosystems that are both intelligent and scalable may be possible as a result of this integration, which might lead to better efficiency, security, and patient outcomes.

Keywords: Cyber; Physical System; Integration; Healthcare; Decision; Support Systems; Artificial Intelligence; Intrusion; Quantum; Predictive; Detection System.

RESUMEN

La convergencia de los Sistemas Ciberfísicos (SCI) y la atención médica está transformando la atención al paciente al reducir la brecha entre los ámbitos digital y físico. Mediante el uso de tecnologías modernas, estos sistemas permiten tomar decisiones inteligentes y obtener información basada en datos en tiempo real.

Introducción: La complejidad de la integración de datos, la mitigación de amenazas cibernéticas sofisticadas y la garantía de la escalabilidad del sistema dentro de una variedad de infraestructuras de atención médica se encuentran entre los obstáculos más importantes.
Método: esta investigación presenta el Sistema de Detección Predictiva Cuántica de Intrusiones con Inteligencia Artificial (AI-IQPDS), un enfoque innovador que busca mejorar la fiabilidad operativa de los CPS de atención médica, así como la seguridad y las capacidades de análisis predictivo del sistema. El AI-IQPDS combina la computación cuántica y el aprendizaje automático para proporcionar una detección precisa de intrusiones y asistencia predictiva en la toma de decisiones. Los sistemas inteligentes de monitorización de pacientes con IA pueden optimizar la gestión de recursos hospitalarios, transmitir datos de forma segura entre dispositivos conectados y detectar emergencias de forma temprana.
Resultados: los resultados de la simulación muestran que el sistema supera las técnicas modernas en cuanto a precisión de detección, velocidad de procesamiento y reducción de falsos positivos. Los resultados de esta investigación demuestran las posibilidades revolucionarias del uso de CPS impulsado por IA en la atención médica.
Conclusiones: como resultado de esta integración podrían ser posibles ecosistemas de atención médica que sean inteligentes y escalables, lo que podría conducir a una mejor eficiencia, seguridad y resultados para los pacientes.

Palabras clave: Cibernético; Sistema Físico; Integración; Salud; Decisión; Sistemas de Soporte; Inteligencia Artificial; Intrusión; Cuántico; Predictivo; Sistema de Detección.

INTRODUCTION

Cyber-Physical Systems (CPS) have the ability to revolutionize healthcare by improving patient care and operational efficiency, however are numerous obstacles to address before their widespread adoption.[1] The primary cause of this is the enormous volume of diverse, multi-dimensional data produced by interconnected medical devices, sensors, and patient monitoring systems.[2] There cannot be consistently obvious standards, which is a problem no matter how crucial it seems that various parts interact and complement each other. The fact that Hospital CPS requires processing and decisions in real-time adds even more strain on existing computational infrastructures. The safety of sensitive information is quite important.[3]

The increasing interconnection of CPS systems poses a number of complex cyber concerns, including advanced hacks such as data leaks and ransomware, which could compromise patient privacy and safety.[4] An increase in the sophistication of solutions capable of providing adaptive and predictive security is imminently necessary.[5] In healthcare CPS, reliable decision support systems are essential since mistakes in diagnostic or treatment suggestions can have devastating consequences.[6] Maintaining accuracy while working quickly appears to be an ongoing challenge. Adapting the CPS frameworks to different healthcare contexts, such as large hospitals or small, resource-constrained rural clinics, is another difficulty. People are afraid to embrace the new technology because of concerns about investment, education, and compatibility with existing infrastructure.[7]

A smarter environment than ever before is being built because of problems that emerging technologies, such AI-based systems, are able to solve.[8] These systems improve healthcare CPS in several ways, especially in terms of efficiency, scalability, and reliability.[9]

Cyber-Physical Systems in healthcare use advanced technologies like the IoT, cloud computing, and artificial intelligence for real-time monitoring, data analysis, and decision support.[10] IoT-enabled wearable sensors and smart medical equipment offer continuous patient monitoring by transferring data across the electronic and physical worlds.[11] AI-powered algorithms increase resource optimization, treatment planning, and predictive diagnoses, and cloud computing scales healthcare data storage and processing. Other cybersecurity methods include blockchain for secure data transactions and anomaly-based IDS. These improvements fail to remove fundamental hurdles.[12]

Traditional IDS seldom detect sophisticated intrusions on IoT devices. Latency and cloud communication breaches raise issues about system reliability and patient record confidentiality.[13] AI models require high-quality annotated data, which is scarce or inconsistent in the health sector can be used. Most systems lack interoperability, making it challenging to combine multiple medical devices and technologies into a single CPS framework. Scalability and adaptability remain challenges, especially in resource-constrained contexts like rural hospitals.

Healthcare providers and patients are resistant to change because they worry about data privacy and AI judgment accuracy. Unique, secure, and adaptable solutions for varied healthcare ecosystems are needed to solve these issues.

The AI-IQPDS has been introduced, which combines quantum computing with artificial intelligence, to improve healthcare CPS intrusion detection and conduct better predictive analytics.

Resolved significant issues with system efficiency and real-time data security, allowing for dependable decision support and secure communication in high-stakes healthcare settings.

Featuring the adaptability of AI-IQPDS in several healthcare domains, including resource optimization, secure device communications, and predictive patient monitoring, providing up the possibility to future scalable solutions.

The following outline the research paper's framework: Healthcare Cyber-Physical Systems Integration is the focus of Section II of this paper. This dissertation's section III delves extensively into AI-IQPDS. An exhaustive examination, a comparison to prior approaches, and an examination of the consequences are presented in Section IV. Section V presents an in-depth study of the findings.

Literature survey

The healthcare sector, among others, benefits from the recent advances that are realized by bringing the ability of AI in fusion with CPS. Mhapsekar, R. U et al.[14] suggested method incorporates Explainable Artificial Intelligence (XAI) in order to improve transparency, trust, and accountability in AI-enabled Cyber-Physical Systems. This method addresses difficulties related to bias, security, and privacy, which ultimately results in decision-making processes that are more dependable. Arbi, A.et al.[15] introduced by exhibiting sensitivity (95,4 %), accuracy (97,2 %), specificity (94,4 %), and precision (96,7 %), the proposed method, which is referred to as Hybrid Support Vector Machines fine-tuned Spatial Transformer Networks (HSVM+FSTN), leads to improved health assessment with higher performance. Srivastava, J et al.[16] proposed through the use of AI-enabled Internet of Medical Things (IoMT) frameworks, the proposed method investigates Cyber-Physical Systems (IoMT-CPS) for Smart Healthcare Systems (SHS), with the goals of increasing continuous health monitoring, resolving security threats, overcoming problems in data management, and optimizing the overall performance of CPS. Khater, H. M et al.[17] proposed for the purpose of enhancing decision-making and improving healthcare outcomes, the suggested method proposes a comprehensive architectural model for integrating Cyber-Physical Systems (AM-CPS) in healthcare. This model addresses difficulties such as interoperability, security, and data processing. When compared to other current strategies, AI-IQPDS provides the best combination of detection accuracy, speed, and security capabilities, making it the most effective option among these methods. Because of this, AI-IQPDS has the ability to greatly enhance the performance and safety of healthcare CPS integration, thereby causing a revolution.

METHOD

Integration of CPS in healthcare transforms the patient care through real-time data-driven insights. This work represents AI-IQPDS; namely, an intrusion quantum prediction and detection system aimed toward enhancing hospital operational dependability, predictive analytics, and CPS security.

Fusion of Quantum Computing and AI

This paper combines quantum computing and machine learning to enhance healthcare CPS. The AI-IQPDS approach provides improved intrusion detection and predictive decision-making capabilities for the problems of cybersecurity for healthcare infrastructure, data integration, and system scalability.

Figure 1 depicts the AI-IQPDS design, an advanced intelligent CPS developed for healthcare applications. The Patient Environment is the starting point of the system, and that is where real-time data is generated. To make sure the data is collected accurately, it passes into the Data Acquisition Layer. The Communication and Networking layer enables safe and smooth transfer of patient information among all the connected devices. Data Integration and Interoperability layers' process heterogeneous streams of data in such a way to ensure that there is consistency scalability from one infrastructure to another. Advanced analytics for obtaining actionable insights useful for clinical applications include advanced visualizations and the AI Decision Support System. Clinical Decision Maker makes use of that insight in predicting, making early emergency identifications, and in hospital resource deployments. The feedback loop in the system will ensure continuous improvement due to Patient Care Interventions & Monitoring and Continuous Feedback, enhancing operational reliability, precision, and security. This architecture embodies the transformational potential of CPS in optimising patient outcomes and efficiency in healthcare is given in equation 1

The suggested system's flexibility L_3 s, safety [g-mnt''], and predictive analytics Ba[dl-pt''] are all seemingly aqc[ð-tr''] represented by the equation 1. The data flow, prediction accuracy, and system performance three critical elements impacting AI-IQPDS are probably correlated with it.

In this equation 2, n_GR might stand for the total number of nodes Baq or linked devices, and W'-3zdf'' could mean either reaction times ð-2aq'' or resource consumption 5vxl''. The goal of this metric is to illustrate how well the system responds to threats while making efficient use of available resources.

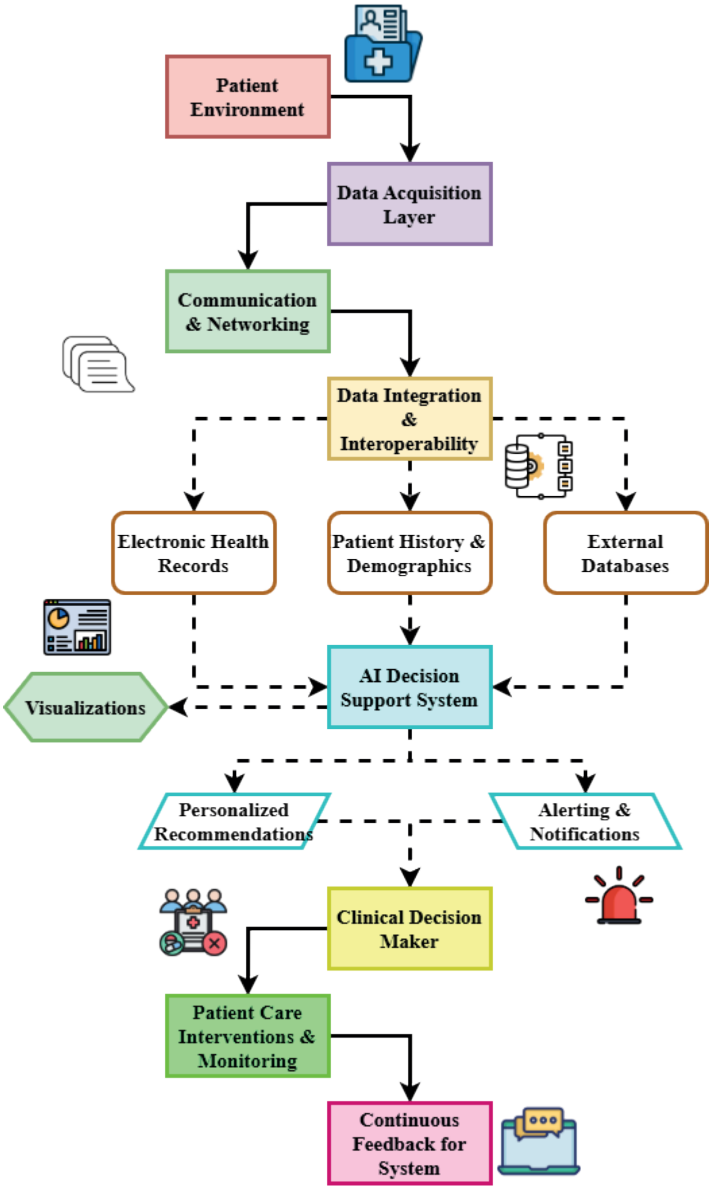

Figure 1. Intelligent Cyber-Physical System Architecture for Healthcare

$$L_3 s[g - mnt'']: \rightarrow Ba[dl - pt''] + aqc[\partial - tr''] \quad (1)$$

$$n_G R[W' - 3zdf'']: \rightarrow Baq[\partial - 2aq''] + 5vxl'' \quad (2)$$

$$\delta_w 2[g - tq'']: \rightarrow Baq[r\nabla - eg''] + 5vaq'' \quad (3)$$

A weighted element or effect associated g-tq” with the use of predictive analytics Baq[r∇-eg”], or system calibration 5vaq” might be represented by $\delta_w 2$ in equation 3, which means the dynamic interaction between different parts in the AI-IQPDS system. Its goal is to clarify how the system’s actions might be optimized to improve accuracy and security in response to data inputs in real time.

$$\propto_{q1} [s - bq'']: \rightarrow NHja[w - fpg''] + w3er'' \quad (4)$$

With $\propto_{q1}$ perhaps representing a scaling factor associated with security measures, s-bq’ and NHja suggesting weighted values for the optimization of systems w-fpg” and real-time predictive functions w3er”, respectively, equation 4 depicts the model's representation of the parameters' interactions. Its goal is to guarantee strong decision-making by measuring the effect of security-related and system changes on the healthcare CPS's.

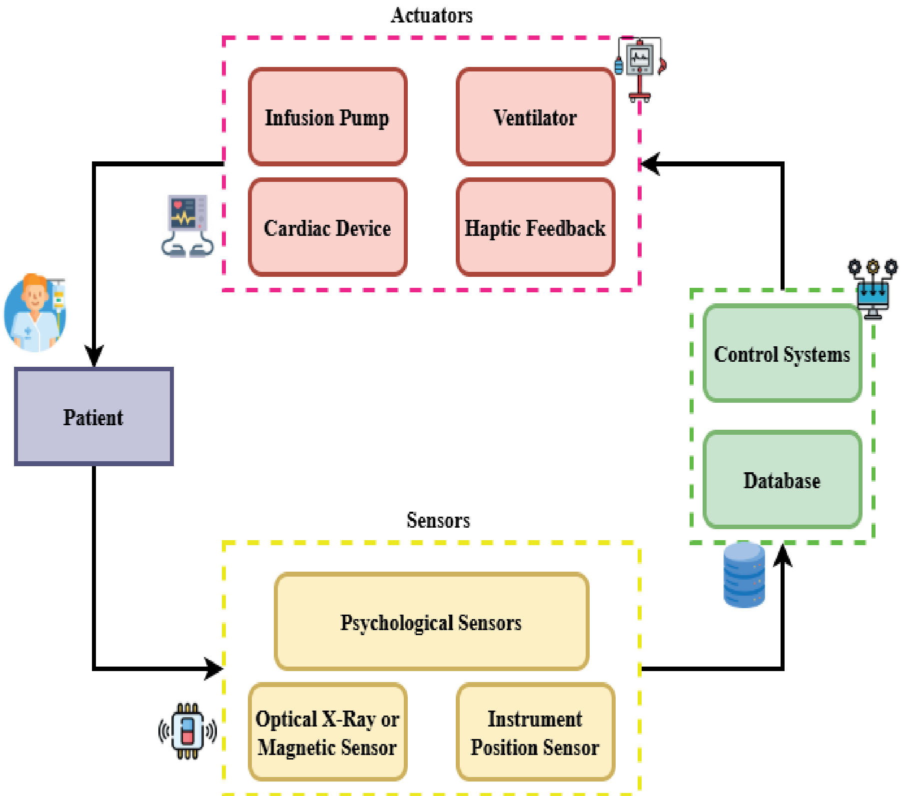

Figure 2. Integrated Sensor and Control Architecture for Healthcare CPS

Figure 2 depicts CPS for healthcare AI-IQPDS, this figure illustrates the sensor and control architecture. Various sensors capture physiological data of the patient at first. To ensure that proper data is captured for real-time monitoring, the following sensors are used: psychological sensors, optical X-ray or magnetic sensors, and position sensors of instruments. Interactions between people and medical equipment, including haptic feedback systems, infusion pumps, ventilators, and cardiac devices, enable accurate therapy. These devices are managed under centralized control systems that ensure that all of them are in sync with each other. A robust database component supports fast and safe access to patient data, thus enabling predictive analytics and decision-making. It meets all the objectives of AI-IQPDS in terms of optimal patient outcomes by virtue of improving data-driven decision support architectures. It ensures scalability within the system, effectiveness of healthcare systems, and active observation.

$$v_{fr}^{lop''} : \rightarrow Kap[2aq' + 3xz''] - bQ[r - vd''] \quad (5)$$

It is possible that the variables $v_{fr}^{lop''}$ and Kap indicate computational adjustments associated with predictive analytics and security bQ[r-vd"], and that the variables 2aq'+3xz" represent factors about system response or efficiency enhancement. Equation 5 is designed to help healthcare organizations enhance the functionality of CPS by modeling the balance between system allocation of resources.

$$V_f r[q - lp''] : \rightarrow Vza[2wer - lpt''] + 2aq'' \quad (6)$$

While $V_f r$ and [q-lp"] represent methods for managing resources and predicting actions 2wer-lpt", the equation 6, Vza might represent 2aq" the impact of current information inputs on system performance. To simulate how real-time data modifications and predictive analytics enhance healthcare CPS system effectiveness and confidentiality, the equation was developed.

$$V_q r[we - kaj''] : \rightarrow Baq[we - kft''] + 2sq'' \quad (7)$$

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The variable $V_q r$ may represent a security and alerting component, we-kaj" a protection adjustment 2sq" or network output, and [we-kft"]+ predictive analytics. When applied to healthcare CPS, this equation will optimize system protection and immediate choice-making by modeling the interaction between security considerations and predictive skills in equation 7.

$$W_2[AF' - Pfq[Lo - rp'']: \rightarrow \; Man[df - sr'] + \; 3aq'' \qquad (8)$$

The variables W_2 and AF'-Pfq in the equation might stand for weights [Lo-rp"] or impact factors connected df-sr' to predictive decision-making Man, system management or modifications to resource allocation 3aq", and analytics-related outcomes, respectively. Equation 8 is meant to represent the process by which the healthcare CPS's operational operations and decision-making capacities.

Implementation of Intelligent Patient Monitoring

AI-based patient monitoring solutions offer safe, efficient device-to-device connectivity while enhancing hospital resource management. The system's real-time emergency detection capabilities significantly improve healthcare outcomes by enabling prompt and accurate responses to critical events.

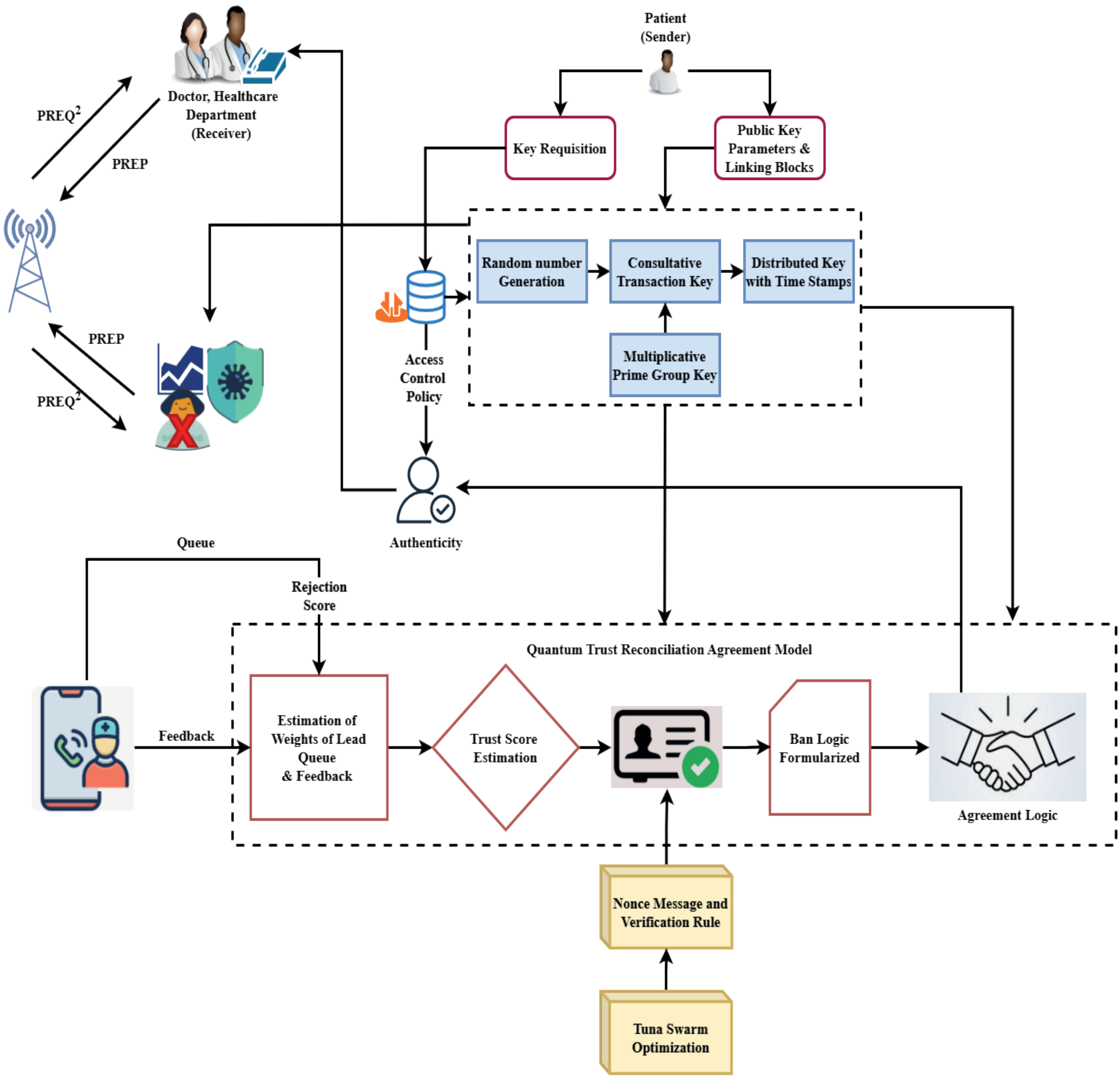

Figure 3. Secure Key Management and Optimization in Healthcare CPS

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The process of managing and optimizing secure keys for healthcare CPS is shown in figure 3. A strong Access Control Policy is put in place for the protection of data pertaining to healthcare professionals and patients from unwanted access and, accordingly, to ensure privacy. Some of the randomized cryptographic approaches that authenticate transactions and secure data transmission are distributed keys with time stamps, multiplicative prime group keys, consultative transaction keys, and random number generation. A dynamic rejection score mechanism evaluates anomalies and flags potential threats for further scrutiny. The Nonce Message and Verification Rule ensures data integrity during communication, while Tuna Swarm Optimization enhances computational efficiency in securing the system against intrusions. The integration of these mechanisms supports secure communication between devices and stakeholders, enabling reliable patient care. This architecture aligns with AI-IQPDS's goal of integrating quantum computing with AI to optimize predictive analytics, intrusion detection, and system reliability in healthcare CPS.

$$f_r t[w - pr'']: \rightarrow Baq[wr - fg''] + 4\,sdr'' \tag{9}$$

The variable $f_r t$ stands for predictive analytics 4 sdr" used for decision support, w-pr" for system security adjustments wr-fg", and the equation 9,Baq for real-time data analysis and threat detection. The goal of the above equation is to simulate the interplay between healthcare CPS optimization, real-time system utilization, security, and analytics for prediction.

$$2_r t[rt - bWQ'']: \rightarrow Ba[wr - gaq''] + 3aqr'' \tag{10}$$

Security adjustments are indicated by 2_r t and predictive outputs are reflected by Ba[wr-gaq"]. The equation 10, [rt-bWQ"]:→ may refer to reaction time or system verification-based 3aqr" on real-time inputs. Equation 10 aims to demonstrate how analytics, security controls, and data processing work together to maximize healthcare CPS.

$$W_2 r[m - bnt'']: \rightarrow Czq[3f - bt''] + 3aq[g - vr''] \tag{11}$$

Equation 11, W_2r might represent a component associated [g-vr"] with system performance and real-time data processing, [m-bnt"]:→ represents security improvements, and Czq[3f-bt"] represents predictive results 3aq used for decision support. This equation aims to show how security measures, predictive analytics, and data management all work together to maximize dependability.

$$w_2 4r[g - nvQ'']: \rightarrow Nq[ft - 3aq''] + 4\,Qa[g - vw''] \tag{12}$$

The weighting factor for system reactivity 4 Qa and threat detection [g-vw"] might be represented by equation 12, w_2 4r, while the predictive outputs and security optimizations are denoted by g-nvQ" and Nq[ft-3aq"] respectively. The goal of this equation is to represent the relationship between analytics, real-time data management, and security measures to guarantee scalability, efficiency, and security.

Figure 4 illustrates the architecture of AI-IQPDS applied to healthcare CPS. It integrates patients in diverse locations (labs, clinics, homes with sensors, or remote areas) with an IoT-enabled mobile device acting as an intermediary. The smartphone safely sends real-time patient data to a web server consequently that extensive analytics may be conducted. Utilizing machine learning and quantum computing, the system detects intrusions and does predictive analytics within an IoT analytics module and control database. All Data Analytics helps doctors monitor and identify early emergencies by visualizing analytical findings. The proposed system architecture includes efficient utilization of hospital resources, streamlined communication, and the ability to make critical decisions quickly and accurately. The model illustrates how AI-enabled healthcare solutions have the ability to revolutionize the industry.

The impact of immediate data processing et-2lsd" and system verification 4 saq" might be shown by equation 13 $r_w k$, and security upgrades and predictive decision-making outcomes are represented by l-pft" and Vaw, respectively. This equation aims to demonstrate how healthcare CPS performance may be optimized via the use of input data, security changes, and predictive analytics.

The system's reaction [tn-3a"] to current data may be represented by equation 14 v_{re}, the combination of safeguards 3XQ" and predictive analytics may be expressed by g-pst", and a result relating to the system's performance es'-pg could be indicated by Naf. Optimized and safe decisions in healthcare CPS are ensured by this equation's purpose to describe the interaction between real-time data on the analysis of intrusion detection accuracy.

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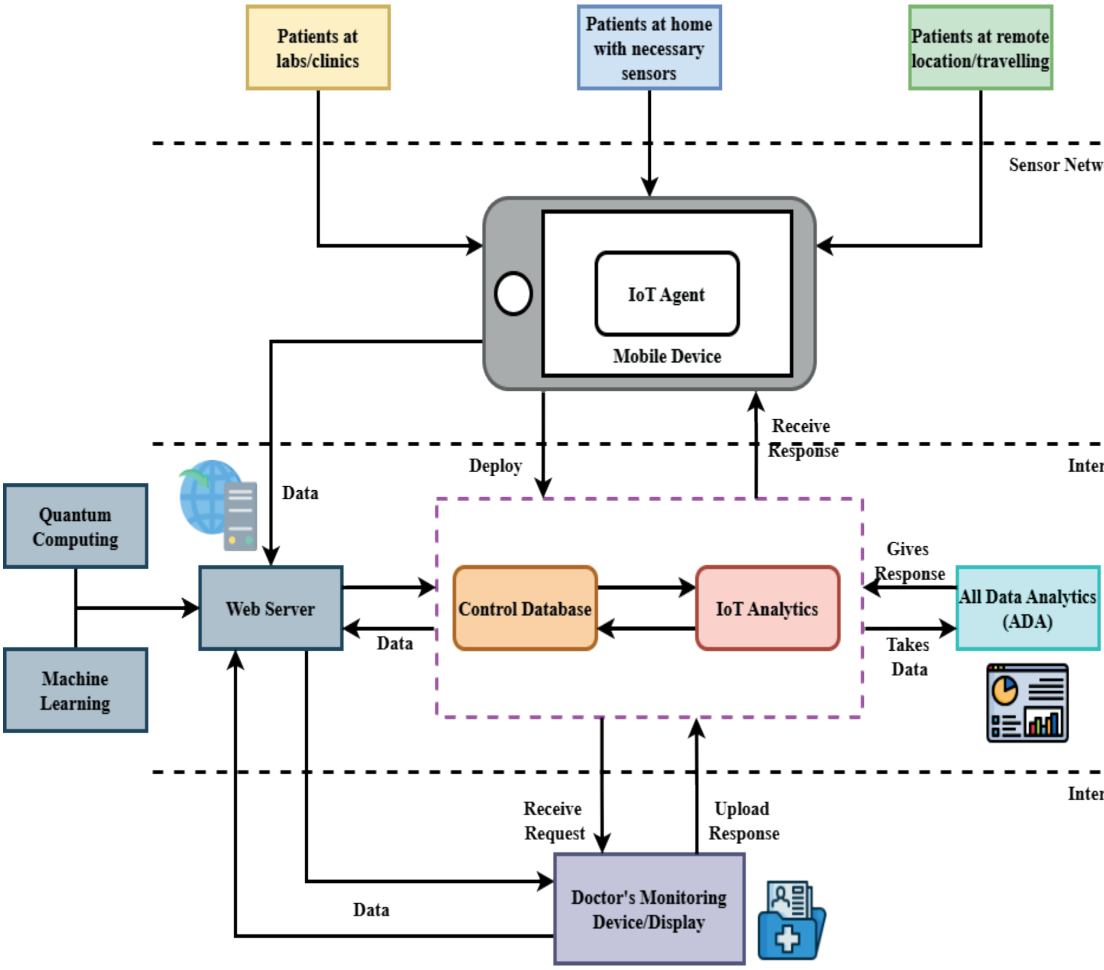

Figure 4. AI-IQPDS for Smart Patient Monitoring and Predictive Analytics

$$r_w k[l - pft'']: \rightarrow Vaw[et - 2lsd''] + 4\,saq'' \quad (13)$$

$$v_{re}[g - pst'']: \rightarrow Naf\left[es' - pg[tn - 3a'']\right] + 3XQ'' \quad (14)$$

$$m_e W[Q - bct'']: \rightarrow Nza[wt' - tsw''] + tw[g - 2a''] \quad (15)$$

The system's processing of data relevant wt'-tsw" to security might be indicated tw by the equation 15 m_eW, a security-enhanced [g-2a"] predictive mechanism by Q-bct", and additional optimizations of the system by Nza. This equation is meant to represent the method by which security measures, predictive analytics, and real-time data processing work together to guarantee peak performance for the analysis of processing speed.

$$r_t t[af - bw'']: \rightarrow Vaq[3fg - pt''] + 6G[r - nt''] \quad (16)$$

Equation 16, r_t t may represent a component associated 3fg-pt^" with data flow and real-time processing in the system, [af-bw"]:→ stands for predictions with security enhancements, and Vaq embodies a sophisticated degree of optimization 6G[r-nt"] and decision-making in the system. Better patient outcomes and overall system performance are the goals of this equation for the analysis of false positive and false negative rates.

Comprehensive Performance Evaluation

Rigorous simulations validate AI-IQPDS, showcasing enhanced detection accuracy, faster processing speeds, and reduced false positives compared to conventional methods. This evaluation underscores the system's potential to revolutionize healthcare CPS by achieving unprecedented reliability and operational excellence.

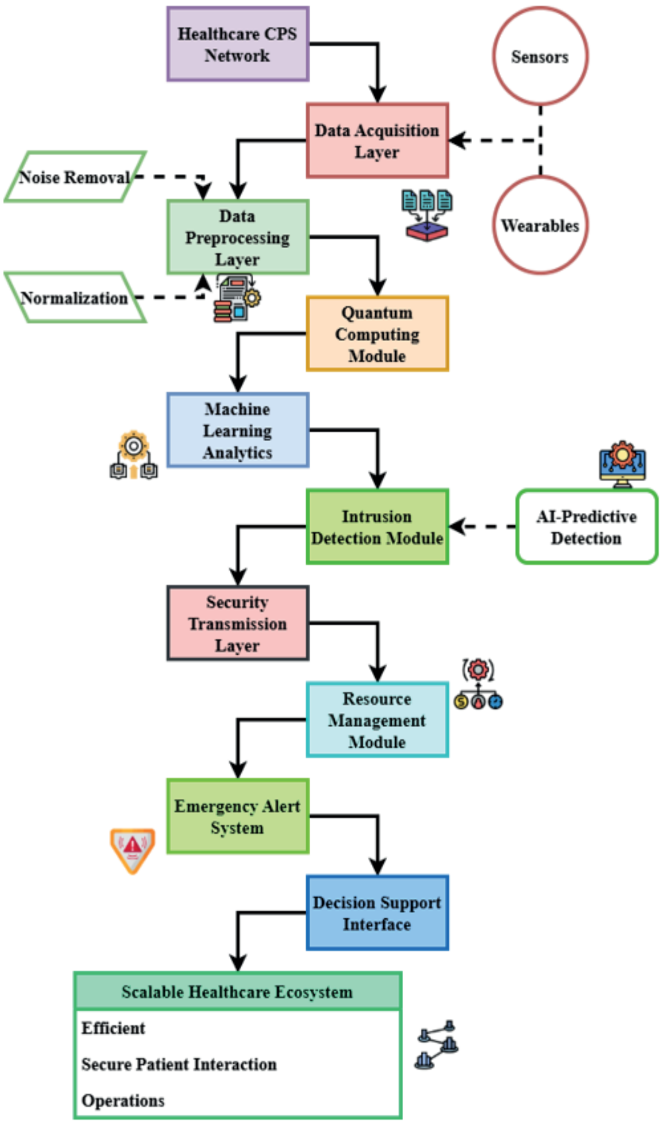

Figure 5. AI-IQPDS Layered Architecture for Secure and Scalable Healthcare Systems

The layered architecture of the AI-IQPDS for healthcare CPS is shown in Figure 5. The Healthcare CPS Network and Data Acquisition Layer collects patient data first. This layer cleans and arranges data, ensuring effective analysis by the Data Pre-processing Layer. The core components of the system, namely the Quantum Computing Module and Machine Learning Analytics, are used to ensure the accuracy of AI-based intrusion detection and predictive decision-making. The Security Transmission Layer ensures protection of data in transit, while the Intrusion Detection Module ensures and highlights intrusion detection. With the help of a Resource Management Module, resource distribution within hospitals will be even better. Emergency alerts are now provided to quickly discover fatal potential events. There is decision support through practical insights given to healthcare practitioners with this system using AI and quantum computing techniques applied to make a Scalable Healthcare Ecosystem efficient with data safety and improved outcomes for the patient.

$$\propto_{et} [eg - mq'']: \rightarrow Nap[n - 2r''] + er[af - bc''] \quad (17)$$

The equation 17, $\propto_{et}$ may indicate a component associated with the adjustment of real-time data processing, Nap denotes the combination of prediction er[af-bc''] and security capabilities, and [n-2r''] shows extra security measures. This equation is meant to represent the relationship between improved system performance, patient care results, and data processing, as well as security advancements for the analysis of resource utilization efficiency.

$$v_{gh}[l - gh']: \rightarrow vaq[3ch - ne''] + 4Sf[m - nq''] \quad (18)$$

The equation 18, v_{gh} may represent a component associated with system calibration 4Sf[m-nq"] and real-time data processing, [̃-gh' shows the results of security-enhanced predictive analysis, and vaq[3ch-ne"] shows further optimization of the system. Integrating real-time data for leadership is the goal of this equation for the analysis of scalability and integration feasibility. AI-IQPDS incorporates quantum computing and machine learning towards improving health-care CPS with a power from these two forces. It improves intrusion detection and reduces the possibility of false positives in intrusion detection. This helps provide securely transmitted data to users. The fact that scalable and intelligent health-care ecosystems have performed satisfactorily in simulations demonstrates that they are capable of enhancing efficiency, safety, and great patient outcome results.

RESULTS AND DISCUSSION

The accuracy of intrusion detection, processing speed, false positive and negative rates, resource usage, and scalability determine the security and efficiency of healthcare CPS. With an increase in interconnected healthcare systems, cyberattacks increase, necessitating stronger and more efficient systems. Quantum computing and machine learning in the AI-IQPDS enhance the accuracy of detection, reduce false alarms, and optimize resource utilization.

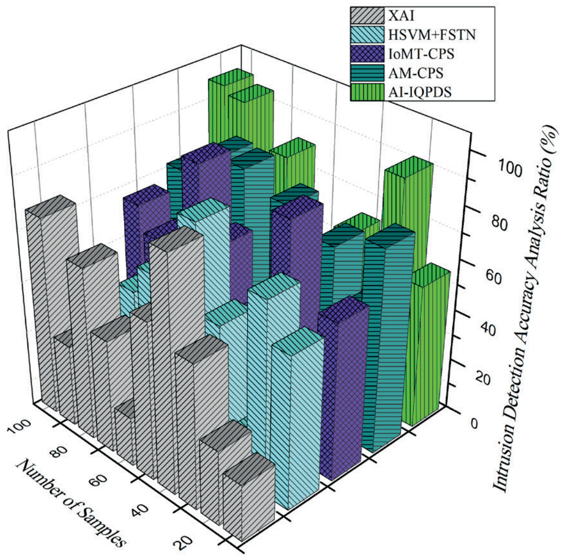

Figure 6. Intrusion Detection Accuracy

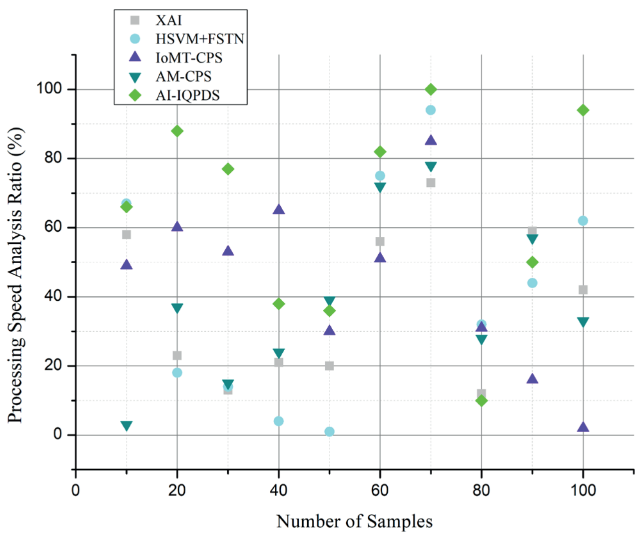

Figure 7. Processing Speed

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In the above figure 6, intrusion detection accuracy is a critical aspect of CPS in healthcare, affecting security and reliability. Interlinking data systems and medical devices increases cyberattack risk in healthcare. This requires robust and accurate intrusion detection. The size and complexity of healthcare CPS challenge typical intrusion detection systems, which increase false positives and negatives. The result is lower system confidence and operational efficiency. Using quantum computing and innovative machine learning, AI-IQPDS solves these issues. This novel technique improves accuracy by detecting existing and emerging threats in real time. Quantum principles help AI-IQPDS examine vast datasets and find minor anomalies that may indicate malicious behavior. Such accuracy lets us respond swiftly to prospective invasions and reduce false alerts. Simulations show that AI-IQPDS has higher detection rates and fewer false positives and negatives than previous approaches. This level of accuracy improves to 98,9 % healthcare CPS reliability and security. AI-IQPDS helps healthcare providers focus on patient care and build confidence in CPS-driven technologies by building the basis.

Real-time processing speeds allow Cyber-Physical Systems to affect patient outcomes. A lot of data is produced daily by linked devices, sensors, and EHRs. Thus, dependable and rapid processing is inevitable. In the above figure 7, in time-critical scenarios, typical system processing inefficiencies might delay decision support. With quantum computing and machine learning, the AI-IQPDS speeds processing. Large datasets can be parallelized via quantum computing, reducing calculation times. AI-IQPDS and advanced machine learning algorithms ensure rapid analysis of complicated healthcare data, including patient monitoring, intrusion detection, and resource allocation. AI-IQPDS outperforms traditional systems in experiments by processing high-dimensional data faster and providing real-time insights. This skill excels in intrusion mitigation, emergency response, and predictive diagnostics in critical situations. Because AI-IQPDS reduces latency and scales, healthcare CPS work effortlessly. Faster and more accurate decisions improve to 94,9 % patient care and system resilience.

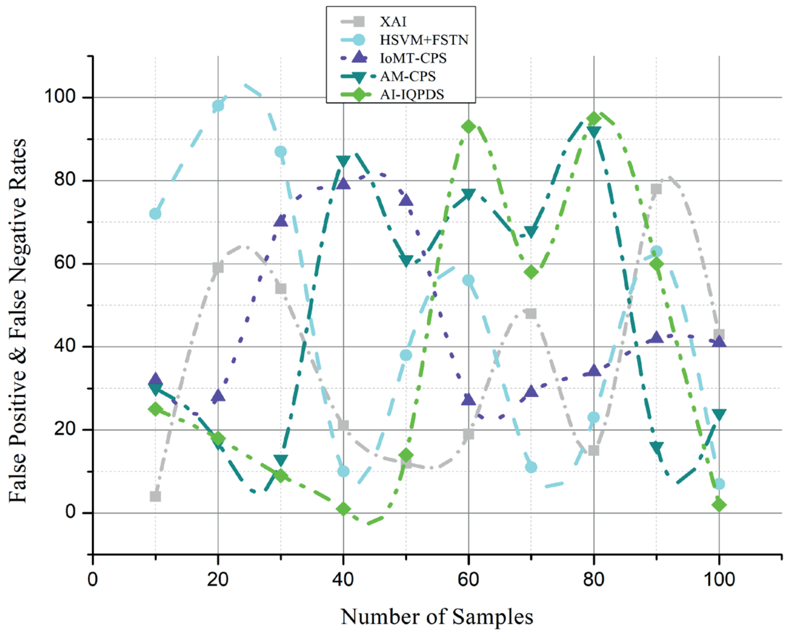

Figure 8. False Positive and False Negative Rates

For trust and efficiency, healthcare CPS intrusion detection systems should have low false positive and negative rates. In the above figure 8, a high false positive rate may exhaust system operators and destroy trust. False negatives may disregard real threats and compromise patient safety and system integrity. Traditional detectors struggle to balance these rates in such a complex and dynamic environment. AI-IQPDS responds using quantum computing and advanced machine learning. It analyses subtle malicious behavior using problem-based predictive modeling to distinguish genuine activities from suspected intrusions, reducing false positives and negatives. AI-IQPDS detects anomalies more accurately and with fewer false alerts than conventional methods per simulation. Since reliability ensures timely and proper attack responses, healthcare CPS security is strengthened. Reduce detection errors to 3,8 % with AI-IQPDS to boost operational efficiency and CPS technology trust in critical healthcare applications.

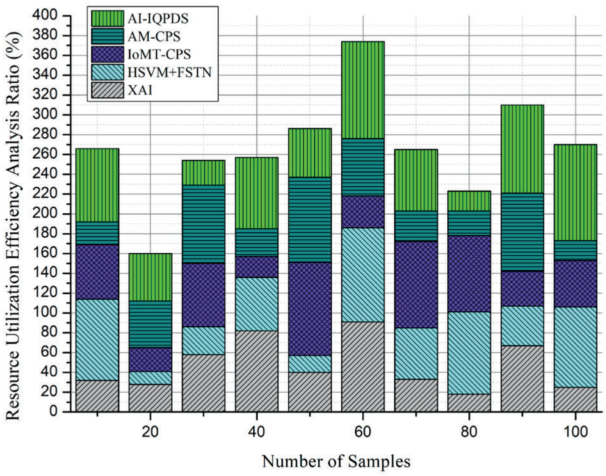

Figure 9. Resource Utilization Efficiency

In the above figure 9, healthcare CPS integration requires resource usage efficiency to improve system stability, scalability, and cost-effectiveness, which impacts patient care. Healthcare CPS often experience high computing demands, redundant data processing, and limited energy resources in dynamic and resource-constrained contexts like remote clinics or emergencies. Many traditional systems lack cognitive resource allocation methods, which leads to inefficiencies and higher operational costs. The simulation of AI-IQPDS demonstrates considerable improvements in computing performance, memory use, and energy savings. These innovations enable health providers to design safe, scalable, and cost-effective systems that maximize resource utilization to 97,4 % and care delivery.

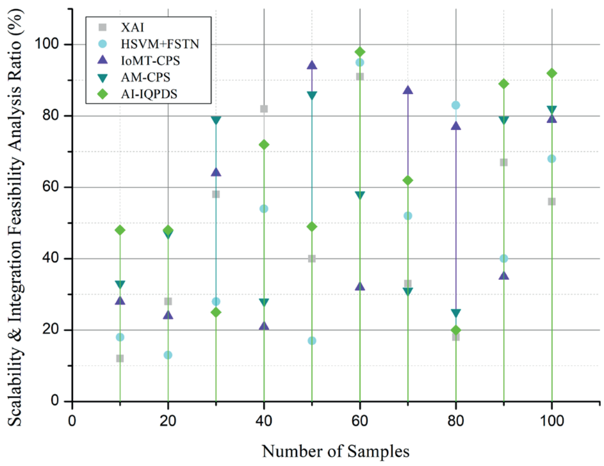

Figure 10. Scalability and Integration Feasibility

In the above figure 10, as healthcare ecosystems change, it becomes more challenging to introduce new technologies and scale systems without compromising dependability or security. Traditional systems are not able to deal with huge data sets or add devices and services. The quantum computing approach to parallel data processing makes large datasets of various devices easier to manage. AI optimizes system performance, thus allowing seamless integration across healthcare platforms, including wearables and hospital monitoring systems. Simulations suggest that AI-IQPDS can easily scale with low latency and high processing rates, thus making it fit for various healthcare contexts. This allows healthcare CPS scalability to 92,8 % and security as systems evolve.

AI-IQPDS improves the accuracy of intrusion detection in healthcare CPS, processing speed, and false positive and negative rates. The system optimizes resource consumption and promotes scalability, assuring stable and secure healthcare environments and providing efficient decision-making and platform integration.

CONCLUSIONS

When combining modern facilities AI with CPS, healthcare will be transformed in future decades. An AI-IQPDS that combines quantum computing with machine learning offers a potential solution to critical issues in healthcare, including cybersecurity, data integration, and scalability. Improving CPS reliability and efficiency with real-time predictive analytics and intrusion detection, AI-IQPDS enables intelligent adaptive ecosystems. According to the results of the simulation, AI-IQPDS performs significantly better than the systems that are already in use, particularly in terms of the accuracy of detection, the speed of processing, and the decreasing rates of false-positives. Its versatility and revolutionary possibilities are demonstrated by its applications in intelligent patient monitoring, safe data transfer, and resource optimization. The research presented here resolves the existing limitations and provides safe, scalable solutions, making the deployment of AI-driven CPS in healthcare settings both feasible and profitable. Combining AI with IQPDS can make healthcare infrastructure more efficient, lead to better patient outcomes, and keep data safe through fostering innovation and enabling better decisions. With the goal to construct healthcare systems that are resilient and flexible, this approach is crucial.

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