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AI-Enabled Internet of Things and Cyber-Physical Systems for Enhanced Disease Detection: A Survey

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Abstract
The incorporation of Artificial Intelligence (AI) with the Internet of Things (IoT) and Cyber-Physical Systems (CPS) offers a significant opportunity in healthcare, especially in improving disease detection and patient well-being. This survey offers a comprehensive overview of recent advancements in AI-driven IoT-CPS for healthcare applications, focusing on enhancing the Quality of Life (QoL) for elderly individuals through real-time health monitoring, disease prediction, and emergency response systems. The survey reviews relevant studies and developments in AI-driven IoT-CPS, specifically in healthcare. The literature selected includes studies on real-time health monitoring, disease detection, and data security. Significant contributions from peer-reviewed journals and conferences are analysed, highlighting advancements and research gaps. Key findings include improvements in IoT and CPS security and progress in real-time health monitoring. However, challenges like accuracy limitations and inadequate security measures in AI-driven IoT-CPS solutions are identified. It emphasizes the requirement of more study and creativity to deal with these challenges and develop reliable systems that provide accurate and secure real-time health monitoring. The survey emphasizes the promising potential of AI-driven IoT-CPS in transforming healthcare while acknowledging existing challenges. Future research should focus on overcoming these challenges through innovative solutions and robust security measures. By addressing these issues, AI-driven IoT-CPS can fulfil their potential in improving disease detection, patient care, and overall healthcare outcomes.

Keywords: *AI-driven IoT-CPS; Disease Detection; Healthcare; Quality of Life; Security.*

1. Introduction

Recently, the convergence of AI, IoT, and CPS has revolutionized various industries [1], with healthcare being a focal point. These cutting-edge technologies possess the capacity to revolutionize conventional healthcare systems [2]. They offer capabilities such as real-time monitoring of patient health metrics, predictive analytics, and tailored interventions crafted specifically for individual needs [3]. Amidst demographic shifts and increasing healthcare demands, the integration of AI-enabled IoT-CPS presents a promising solution to enhance disease detection and patient care [4]. Understanding the dynamics of AI-enabled IoT-CPS in healthcare is more pertinent than ever. Recent technological advancements, coupled with growing concerns about healthcare accessibility and quality, underscore the importance of exploring innovative solutions. By leveraging the capabilities of AI-driven IoT-CPS, healthcare professionals can revolutionize their practices. This integration enables them to optimize workflows, enhance diagnostic precision, safeguard sensitive patient information [5], and, most importantly, elevate patient care results. In this survey, AI-enabled IoT-CPS integrates artificial intelligence techniques with interconnected devices and systems, enabling intelligent decision-making and automation in healthcare settings. Disease detection involves a multifaceted process to identify existing health conditions and foresee potential ailments, spanning the spectrum from enduring chronic illnesses to sudden, urgent emergencies. Patient well-being enhancement entails proactive

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measures to enhance overall wellness and happiness. The primary purpose of this survey is to offer an extensive overview of recent developments in AI-driven IoT-CPS for healthcare applications, with a specific focus on disease detection and patient well-being enhancement. By thoroughly synthesizing the corpus of existing literature, the survey endeavours to shed light on pivotal contributions, pinpoint areas lacking research, and pave a clear path towards future exploration in this rapidly expanding domain. This survey encompasses a wide spectrum of studies and advancements in AI-enabled IoT-CPS within the healthcare domain. Included research covers real-time health monitoring, disease prediction, and data security to offer a holistic understanding of the topic. Nonetheless, it's critical to recognize the fundamental shortcomings of survey methodology, such as the potential for bias in literature selection and the dynamic nature of technological advancements. The remaining sections of this survey are arranged below: The Literature Survey offers a comprehensive review of significant contributions and research gaps within AI-enabled IoT-CPS for healthcare, providing a foundational understanding of the field. Secondly, the Proposed System section delves into the intricacies of a novel AI-enabled IoT-CPS system crafted to elevate disease detection capabilities and improve patient well-being, offering insights into its design and functionality. Lastly, the Conclusion segment encapsulates key findings and implications drawn from the research. It suggests avenues for future exploration, thereby wrapping up the paper with a cohesive summary and outlining potential directions for further investigation.

2. Literature Survey

Integrating AI with the IoT and CPS has garnered significant attention in recent research. This literature survey reviews key contributions, objectives, and research gaps identified in recent studies to understand the current landscape and future directions for AI-enabled IoT-CPS, especially in healthcare. Ramasamy et al. [1] address the critical need for secure smart wearable computing in health monitoring by integrating AI-enabled IoT and CPS. Their study highlights the potential of AI-driven IoT-CPS to significantly enhance the security and accuracy of wearable computing devices used in health monitoring applications. However, it identifies the significant gap, highlighting insufficient accuracy and limited security measures as key areas for improvement. Albasir et al. [2] discuss the critical security challenges associated with IoT and CPS devices, proposing AI-driven approaches to enhance security measures. The study emphasizes the importance of AI in identifying and mitigating security threats in real time. However, the research primarily focuses on general IoT and CPS applications and does not delve deeply into specific applications in healthcare. Salau et al. [3] comprehensively survey recent advancements in AI applications for wireless IoT and CPS. They highlight how AI enhances these systems' efficiency and capabilities, including smart healthcare applications. The authors identify a significant gap in integrating AI for real-time health monitoring and disease detection, suggesting a need for further research in these areas. Radanliev et al. [4] explore the concept of digital twins in the context of AI and IoT-CPS within the Fourth Industrial Revolution. Their work discusses how digital twins can simulate and optimize industrial processes, contributing to predictive maintenance and operational efficiency. While their study offers valuable insights into industrial applications, it does not extensively cover healthcare applications of digital twins in IoT-CPS. Haldorai [5] reviews AI's role in enhancing IoT and CPS, covering various sectors, including healthcare. The review highlights AI's potential in improving system intelligence and autonomy. However, it identifies the need for more focused research on the ethical implications and data privacy concerns specific to healthcare applications. Andronie et al. [6] investigate AI-based decision-making algorithms and their integration with IoT sensing networks in CPS. Their study showcases deep learning's use in intelligent process management, particularly in industrial settings. Although the research provides a foundation for smart decision-making, a notable research gap exists in applying these algorithms to enhance disease detection in healthcare IoT-CPS. The works of these authors are comparatively analyzed in Table 1.

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Table 1 Comparative Assessment

Sr. No	Paper Title	Author(s)	Publication	Contribution/Objectives	Research Gap
1	Secure smart wearable computing through artificial intelligence-enabled Internet of Things and cyber-physical systems for health monitoring.	Ramasamy et al. [1]	Sensors, 2022	AI-driven IoT-CPS enhance secure wearable computing for health monitoring	Insufficient accuracy and limited security measures
2	Toward improving the security of IoT and CPS devices: An AI approach	Albasir et al. [2]	Digital Threats: Research and Practice, 2023	AI-driven security enhancements for IoT and CPS	Lacks focus on healthcare applications
3	Recent advances in artificial intelligence for wireless Internet of Things and cyber-physical systems: A comprehensive survey	Salau et al. [3]	IEEE Internet of Things Journal, 2022	Survey of AI applications in wireless IoT and CPS	Need for research on real-time health monitoring and disease detection
4	Digital Twins: Artificial Intelligence and the IoT cyber-physical Systems in Industry 4.0	Radanliev et al. [4]	International Journal of Intelligent Robotics and Applications, 2022	Discussion on Digital Twins in the Fourth Industrial Revolution	Limited coverage of healthcare applications
5	A Review on Artificial Intelligence in the Internet of Things and Cyber-Physical Systems	Haldorai [5]	Journal of Computing and Natural Science, 2023	Review of AI's role in enhancing IoT and CPS	Need for focused research on ethical implications and data privacy in healthcare.
6	Artificial intelligence-based decision-making algorithms, Internet of Things sensing networks, and deep learning-assisted smart process management in cyber-physical production systems	Andronie et al. [6]	Electronics, 2021	AI-based decision-making and deep learning in CPS	Research gap in applying these algorithms for disease detection in healthcare IoT-CPS

This detailed literature survey highlights significant contributions and existing gaps in the research on AI-enabled IoT-CPS. By understanding these gaps, future research can focus on addressing specific challenges in healthcare applications, thereby advancing the field and improving disease detection and patient care.

3. Research Gap Identified & Probable Solutions

The proposed system is an AI-enabled IoT-CPS designed to enhance healthcare services for elderly individuals. The system aims to boost the life quality of elderly individuals, especially those whose family members are occupied with work during the day,

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while reducing medical costs. This section details the IoT-CPS application, security mechanisms, and AI algorithms for disease detection and prediction. Figure 1 showcases the system setup of AI-driven IoT-CPS.

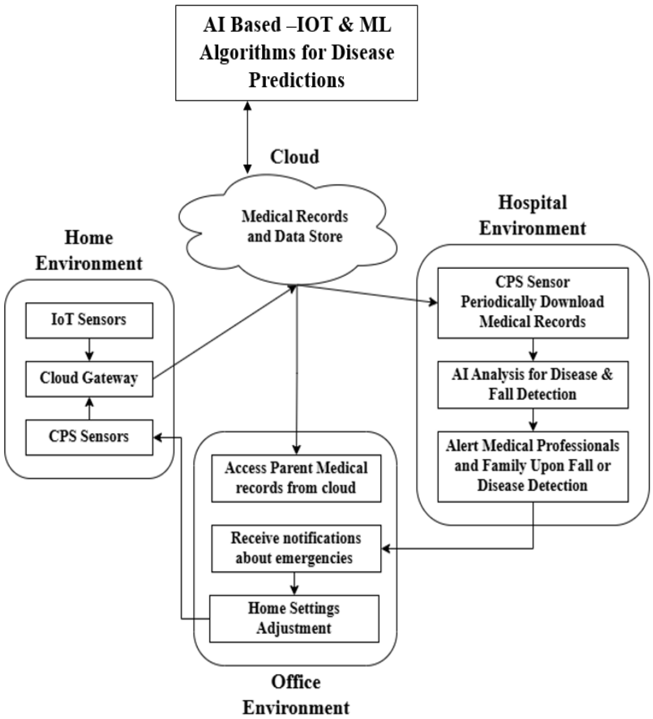

Figure 1 System setup of AI-driven IoT-CPS

The AI-driven IoT-CPS system comprises three primary environments: home, hospital, and office.

- **Home Environment:** At home, an older adult's daily physical, medical and environmental data are collected using various IoT and CPS sensors [7], [8]. This data is transmitted to a central cloud storage via Cloud Gateway [9].
- **Hospital Environment:** CPS sensors in the hospital environment periodically download stored medical records from the cloud at specific intervals. It can review medical records regularly and apply AI algorithms to detect potential diseases [10], [11]. Based on the AI analysis, medical professionals can provide suggestions, prescriptions, and necessary interventions [12]. In emergencies, such as a fall, the CPS sensor promptly alerts the medical professionals and the family members, enabling immediate action [13].
- **Office Environment:** The family members of the older adults working in their offices can access the medical records stored in the cloud. They can monitor their parents' health status, receive timely notifications regarding any abnormal conditions or emergencies [14], [15], and adjust home settings through CPS sensors. For instance, they can automatically turn on lights upon detecting motion and unlock doors to facilitate access for paramedics.

3.1.Security Mechanisms

Ensuring security and trust in IoT-CPS is crucial for user acceptance. Comprehensive security mechanisms are implemented in the proposed system to shield highly confidential information from cyber-attacks and illegal access.

- **Public and Private Key Encryption:** The older adult's son generates public and private keys [16]. The public key is shared with all wearable devices, and the private key is given to the hospital's duty doctor. It ensures that the data collected by the devices is encrypted using the public key and can solely be decrypted by permitted users utilizing the private key.

3.1.1. Data Encryption and Decryption Process

1. **Data Collection:** Wearable devices collect health data and encrypt it using the public key.
2. **Data Transmission:** Encrypted data is sent to the cloud and shared with the son's office and the hospital.
3. **Data Access:** The son and the doctor use the private key to decrypt and access the data, ensuring only authorized personnel can view sensitive information.

3.2.AI Algorithms for Disease Detection and Prediction

The proposed system uses AI to analyze collected health data and detect diseases at an early stage. It focuses on identifying chronic diseases like diabetes, cardiovascular disease, Diabetes and Heart disease using datasets from the UCI machine learning repository. Additionally, the system incorporates fall-

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detection capabilities. Datasets Available for Research:

- **Cstick-Elderly Fall Prediction and Detection Dataset:** This dataset includes data for predicting and detecting falls among older people. It contains various sensor readings and can be accessed at Kaggle.
- **Heart Failure Prediction Dataset:** This dataset is designed for predicting heart failure based on clinical features such as age, gender, blood pressure, and other medical parameters. Available at Kaggle.
- **Easiest Diabetes Classification Dataset:** This dataset is used for classifying diabetes, containing features like BP, concentrations of glucose and insulin, dermal depth, and additional aspects. It can be accessed at Kaggle.

3.2.1. Explanation of AI Algorithms

The system employs various AI algorithms, for disease discovery and prediction. These algorithms are trained on labelled datasets to discover the traits and trends connected to certain illnesses. During the training phase, our system processes a part of the dataset to build predictive models. These models are then validated and further tested on different data subsets for evaluating their accuracy and performance. The system arranges its parameters to improve reliability by comparing the predicted outcomes with the actual diagnoses. Table 2 shows few AI algorithms that are used for disease detection.

Table 2 AI Algorithms Used for Disease Detection

Algorithm	Pros	Cons
Convolutional Neural Networks (CNN)	CNNs are a type of deep learning model tailored for analyzing structured grid-patterned data, particularly pictures. They comprise layers of convolutions, pooling, and fully connected nodes, making them highly effective for interpreting image-based health data.	Requires large amounts of labeled data
Recurrent Neural Networks (RNN)	RNNs are structured to handle sequential data by preserving information from earlier inputs. They excel at analyzing data that unfolds over time, such as physiological signals or patient records.	Captures temporal dependencies in data
Support Vector Machines (SVMs)	SVMs are precise AI models that perform well in high-dimensional spaces. They are used for classification and regression by identifying the best separating hyperplanes.	Not suitable to handle large datasets along with high dimensionality
Random Forest	Random Forest, an AI-powered ensemble learning method, combines multiple decision trees for classification and regression tasks, enhancing accuracy and robustness.	Can be computationally expensive for large datasets

In addition to disease detection and prediction, the system integrates fall detection algorithms. These algorithms analyze data from sensors, including motion sensors and accelerometers, and can detect trends that point to falls.

3.3. Cloud Platforms

Choosing a cloud platform for hosting IoT-CPS applications is critical as it directly impacts performance, scalability, security, and cost-effectiveness. Performance considerations include the responsiveness and efficiency of data processing, device communication, and real-time analytics. Scalability is essential to accommodate many devices and increase data volumes without compromising performance. Security is paramount, ensuring data privacy, secure device communication, and compliance with industry regulations. Lastly, cost-effectiveness involves balancing the expenses associated with cloud services, data storage, and processing against the value derived from the IoT-CPS application. Table 3 compares some cloud platforms.

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Table 3 Comparison of Cloud Platforms

Cloud Platform	Pros	Cons
Amazon Web Services	Highly scalable, comprehensive services, robust security	Can be expensive, Complex pricing structure
Microsoft Azure	Seamless integration with Microsoft products, good hybrid cloud capabilities	Complex pricing model, occasional downtime
Google Cloud Platform	Strong AI and machine learning tools, cost-effective	Fewer global data centres compared to competitors

3.4.Need for AI-driven IoT-CPS Systems

Integrating AI-driven IoT and CPS in healthcare is essential to address the growing needs of an ageing population. These advanced systems utilize interconnected devices and intelligent algorithms for continuous health monitoring, early disease detection, and timely medical interventions. By collecting and analyzing real-time health data through sensors and wearable devices, these systems enable proactive healthcare management, reducing the risk of complications and hospitalizations. Personalized treatment plans tailored to individual patients enhance the effectiveness of medical interventions, leading to better patient outcomes. Furthermore, remote healthcare services offered by these systems improve accessibility for older patients, particularly those who live in remote places or have mobility challenges. By preventing emergencies and managing chronic diseases more efficiently, AI-enabled IoT-CPS systems help reduce healthcare costs, making resource allocation more effective.

3.4.1. Statistical Analysis

The World Health Organization (WHO) stated that in 2019, around 702.9 million individuals aged 65 and above were recorded, with projections indicating this figure will surpass 1548.9 million by 2050. Similarly, the population of those aged 80 and older is anticipated to rise substantially to 426.4 million by 2050 from 143.1 million in 2019. This dramatic rise highlights the ongoing demographic shift towards an ageing global population, with implications for various sectors, including healthcare. Table 4 shows these statistics on the elderly population and healthcare needs.

Table 4 Statistics on Elderly Population and Healthcare Needs

Year	Global Elderly Population (65+)	Global Elderly Population (80+)
2019	702.9 million	143.1 million
2050	1548.9 million	426.4 million
Healthcare Expenditure Increase (%)	**120.36%**	**197.97%**

Furthermore, Figure 2 shows the pictorial diagram of this growth of the elderly population (2019-2050) as a line chart.

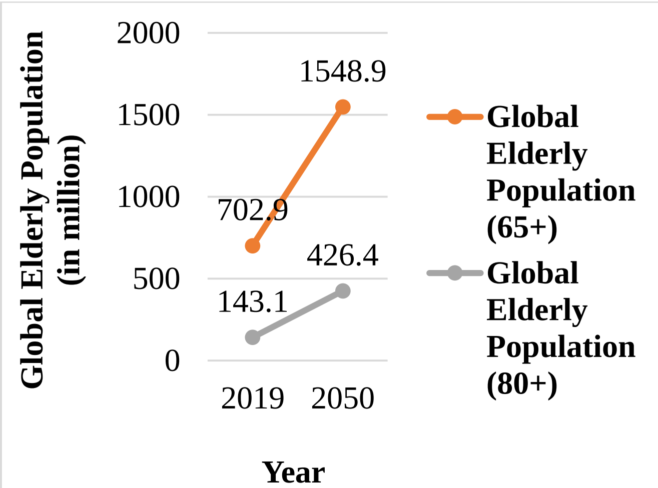

Figure 2 Growth of Elderly Population (2019-2050)

The increase in healthcare expenditure associated with the growing elderly population is also significant. Figure 3 shows the pictorial diagram of this increase as a bar chart. The chart indicates that healthcare spending is projected to rise by 120.36% for the general elderly population (65+) and an even more pronounced 197.97% for those aged 80 and older . This steep increase in healthcare costs reflects

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the greater medical needs and more intensive healthcare services required by older adults, particularly those in the 80+ age group who are more likely to have chronic conditions and complex health issues. These statistics underscore the need for innovative healthcare solutions to manage the increasing burden of chronic diseases and ensure the well-being of older adults. Given the anticipated rise in the elderly population and corresponding healthcare expenditures, an AI-enabled IoT-CPS system is proposed to enhance healthcare services for elderly individuals. Implementing AI-enabled IoT-CPS systems can significantly improve healthcare delivery by providing real-time health monitoring, reducing hospital readmissions, and enabling personalized care. These systems also alleviate the pressure on healthcare providers by automating routine tasks and facilitating remote patient monitoring. The proposed AI-enabled IoT-CPS system offers a comprehensive approach to improving healthcare for elderly individuals by integrating advanced AI algorithms for disease detection and prediction, robust security mechanisms, and seamless connectivity across home, hospital, and office environments. This system enhances the QoL for older adults, provides peace of mind for their families, and ensures timely medical intervention, ultimately reducing healthcare costs and improving overall healthcare efficiency. In assessing the performance of classification algorithms for disease prediction, a few existing studies, especially Ramasamy et al. [1], have reported on the effectiveness of different approaches. Table 5 summarizes the comparative performance of several classification algorithms across four key metrics: Accuracy, Precision, Recall, and F-Measure, specifically in the context of disease prediction.

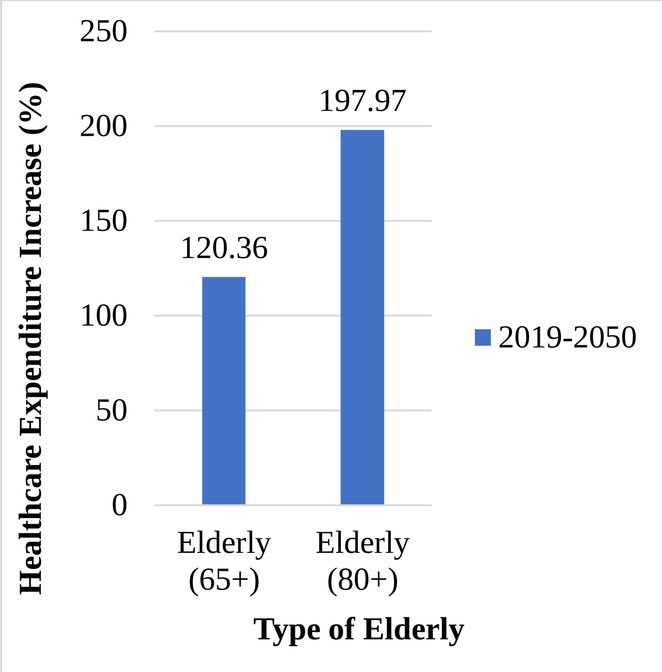

Figure 3 Growth of Healthcare Expenditure Increase

Table 5 Performance Comparison of Classification Algorithms for Disease Prediction

Algorithm	Accuracy (%)	Precision (%)	Recall (%)	F-Measure (%)
Naive Bayes	83.5	83.8	83.7	83.6
SVM	83.9	83.7	83.9	83.9
KNN	75.0	75.7	75.6	75.7
ANN	78.9	78.2	78.4	78.3
AI-enabled IoT-CPS	85.1	86.3	86.5	86.4

These metrics provide valuable insights into the comparative performance of classification algorithms as reported in existing literature, shown in Figure 4. Naive Bayes and SVM demonstrate similar performance levels, with SVM slightly outperforming Naïve Bayes regarding accuracy, recall and F-measure. Conversely, KNN exhibits comparatively lower performance across all metrics, indicating potential limitations for disease prediction tasks. While showing moderate effectiveness, ANN falls short of Naïve Bayes and SVM in terms of overall performance.

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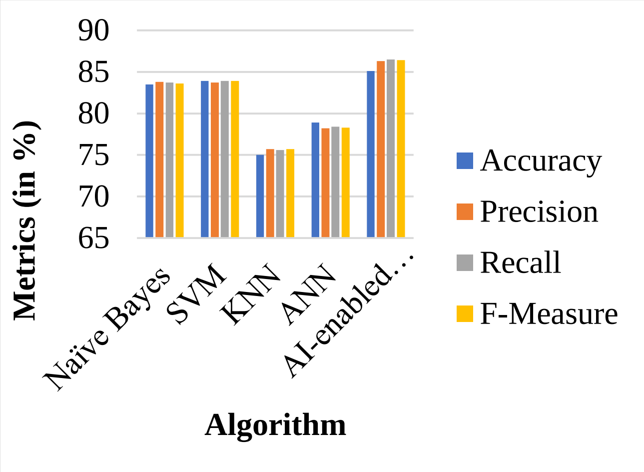

Figure 4 Comparative Analysis of Classification Algorithm Performance for Disease Prediction

The AI-enabled IoT-CPS model is the most promising approach, consistently surpassing other algorithms across all metrics. It suggests that integrating AI with IoT-CPS technology significantly improves disease prediction, making it highly effective for healthcare applications. The AI-driven IoT-CPS system offers a comprehensive approach to improving healthcare for elderly individuals by integrating advanced AI algorithms for disease prediction, robust security mechanisms, and seamless connectivity across home, hospital, and office environments. This system enhances the quality of life for older adults, provides peace of mind for their families, and ensures timely medical intervention, ultimately reducing healthcare costs and improving overall efficiency. [17-19]

Conclusion

In conclusion, this survey offers a thorough overview of recent advancements in AI-enabled IoT-CPS for healthcare, focusing on disease detection and patient well-being enhancement. The integration of AI-driven IoT-CPS holds promise for revolutionizing healthcare delivery by offering real-time monitoring and personalized interventions to improve patient outcomes and reduce costs. This survey has solved several important problems. It has combined scattered research into one comprehensive review, provided a detailed analysis of how AI optimizes disease prediction in healthcare systems, and summarized the latest developments in AI-driven IoT-CPS. While valuable, this survey acknowledges limitations such as overlooking emerging trends and biases inherent in literature selection and scope limitations. Future research should focus on overcoming accuracy and security challenges, exploring novel applications, and fostering interdisciplinary collaborations to realize the potential of AI-driven IoT-CPS in healthcare fully. Through continued innovation and collaboration, the full potential of AI-driven IoT-CPS can be harnessed to improve healthcare outcomes and enhance patient well-being. Also through AI-Enabled Internet of Things and Cyber-Physical Systems for Enhanced Disease Detection.

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