AI, BIG DATA, AND HEALTHCARE

DATA-DRIVEN APPLICATIONS

PART 1



Editors:
D. Arul Kirubakaran
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AI, Big Data, and Healthcare: Data-Driven Applications

(Part 1)

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FOREWORD

In the era of digital transformation, the integration of Artificial Intelligence (AI), Big Data, and Industry 4.0 technologies signifies more than a technological evolution—it marks a profound scientific revolution that is reshaping how we understand, engage with, and address complex real-world challenges. This transformation is particularly significant in sectors such as healthcare and manufacturing, where data-driven intelligence and automation are redefining the benchmarks of service delivery and production efficiency.

The book "*AI, Big Data, and Healthcare Data-Driven Applications*" provides a comprehensive and timely examination of these emerging domains. From a scientific standpoint, it compiles carefully selected research contributions that highlight the growing interplay between advanced computational methods and domain-specific problem-solving. Each chapter reflects how the integration of scientific rigor with technological innovation can drive advancements in diagnostics, predictive analytics, and operational performance.

The convergence of AI and Big Data analytics offers a robust framework for uncovering intricate patterns and relationships within complex datasets. This capability enables early disease detection, precision medicine, and personalized healthcare solutions. These advancements are supported by developments in machine learning, deep learning, and natural language processing, which are increasingly achieving performance levels comparable to human expertise in clinical diagnostics and decision support systems.

Simultaneously, Industry 4.0 and the Industrial Internet of Things (IIoT) are revolutionizing traditional manufacturing by enabling intelligent, adaptive, and interconnected systems. Through real-time data acquisition and AI-driven decision-making, these technologies enhance operational efficiency, optimize resource utilization, and improve product quality, thereby advancing the transition toward autonomous manufacturing ecosystems.

The book addresses several key scientific themes, including predictive and descriptive analytics in healthcare, AI-driven diabetes prediction models, deep learning applications in medical imaging, IoT-enabled health monitoring systems, and analytical approaches to biotechnology security. It also examines the evolution of digital healthcare initiatives in India, the role of AI in mental health assessment, and the application of smart manufacturing and IIoT within modern industrial frameworks.

More than a conventional reference, this volume serves as a strategic guide for researchers, practitioners, and policymakers navigating the rapidly evolving landscape of data-centric technologies. By bridging disciplines such as computer science, healthcare, biotechnology, and industrial engineering, it promotes an integrated perspective on the transformative potential of AI and Big Data.

In addressing global challenges that demand intelligent, efficient, and reliable solutions, this book aims to foster innovation, collaboration, and critical thinking. It underscores the importance of collective scientific effort in advancing the capabilities of AI for societal benefit and shaping a more informed and technologically empowered future.

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PREFACE

The accelerated progress in Artificial Intelligence (AI), Big Data, and Industry 4.0 technologies has triggered significant transformations across multiple domains, particularly in healthcare and manufacturing. AI-powered advancements are enhancing diagnostic precision, enabling predictive analytics, and driving automation, thereby improving patient outcomes and optimizing industrial operations. The fusion of AI with Big Data analytics offers a powerful framework to tackle critical healthcare challenges, including early disease detection, precision medicine, and personalized treatment planning. In parallel, the advent of Industry 4.0 and the Industrial Internet of Things (IIoT) is reshaping manufacturing systems, leading to improved efficiency, productivity, and intelligent process control.

This book, *AI, Big Data, and Healthcare Data-Driven Applications*, presents a curated collection of research contributions that explore state-of-the-art developments in AI and Big Data, with a strong emphasis on healthcare and manufacturing applications. The chapters cover a broad spectrum of topics, including predictive analytics, AI-driven diagnostic systems, deep learning techniques, IoT-enabled health monitoring, and the integration of robotics within modern manufacturing environments.

The volume highlights several key scientific themes:

Key scientific themes include:

• Predictive and Descriptive Analytics in Healthcare – Demonstrating how AI-based analytics enhance diagnostic accuracy and support effective treatment planning.

• AI Innovations in Predictive Diabetes Care – Utilizing machine learning models for early detection and improved management of diabetes.

• Deep Learning in Medical Imaging – Exploring advanced techniques for pneumonia detection using X-ray images and deep learning applications in endodontics.

• IoT in Healthcare Monitoring – Examining the role of IoT technologies in monitoring conditions such as sleep apnea and enabling real-time health tracking.

• Biotechnology Safety and Security Measures – Evaluating global biosecurity frameworks through qualitative analysis and clustering approaches.

• Healthcare Transformation in India – Analyzing the impact of digital health initiatives, including e-hospitals, online registration systems, and AI-driven services.

• Mental Health and AI – Investigating AI-based tools for detecting and monitoring depression, particularly in patients with coexisting conditions like hypertension and diabetes.

• Industry 4.0 in Manufacturing – Assessing smart manufacturing systems, automation strategies, and the influence of IIoT on modern industrial practices.

Designed as a comprehensive resource, this book caters to researchers, healthcare practitioners, industry professionals, and students interested in the convergence of AI, Big Data, and applied technologies. By integrating insights from diverse disciplines, it undersco-

res the transformative potential of AI in enhancing healthcare delivery and advancing manufacturing systems.

As AI and Big Data continue to redefine conventional paradigms, this volume serves as a timely reference, offering valuable perspectives on innovation and technological progress. It aims to inspire further research, foster interdisciplinary collaboration, and support the development of intelligent solutions for complex global challenges.

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CHAPTER 1

Introduction and Overview of AI, Big Data, and Data-driven Applications in Healthcare

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Abstract: Advances in medical imaging, diagnostics, illness prediction, and patient care are made possible by the combination of Artificial Intelligence (AI) and Machine Learning (ML), which is transforming the healthcare industry. The revolutionary role of AI-driven technology in a range of healthcare applications, such as real-time monitoring, predictive analytics, and early illness identification, is examined in this chapter. In highlighting the potential of Machine Learning (ML) in medical imaging, endodontics, pneumonia detection, and sleep apnoea diagnosis, the research shows how AI improves accuracy, efficiency, and treatment results. It also looks at how AI is used in India's healthcare, biosecurity, and biosafety sectors, highlighting how it may help with decision-making and accessibility. The Industrial Internet of Things (IIoT) and Industry 4.0 are also covered, demonstrating how AI improves healthcare automation and manufacturing. Notwithstanding the noteworthy advantages, issues including algorithmic bias, data privacy, and integration into therapeutic contexts still exist. Realising AI's promise to revolutionise healthcare delivery and enhance patient outcomes requires addressing these problems.

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Keywords: Artificial Intelligence (AI), Big data, Biosecurity and biosafety, Cyber-physical systems, Deep Learning (DL), Diabetes prediction, Healthcare technology, Industry 4.0, Internet of Things (IoT), Machine Learning (ML), Medical imaging, Parkinson's disease diagnosis, Pneumonia detection, Predictive analytics, Wearable devices.

INTRODUCTION

The traditionally specialised profession of medical imaging might undergo a transformation because of the fast-developing discipline of Machine Learning (ML). Large volumes of data are used by machine learning algorithms to help computers learn and spot patterns, resulting in remarkably accurate predictions. Numerous advances in medical imaging, such as Computer-Aided Detection (CAD), diagnosis, picture segmentation, and image registration, have been made possible by this capacity. More accurate diagnoses and better treatment plans may be made possible by Machine Learning (ML), which may reveal tiny patterns in pictures that are often too complicated for the human eye to see. By examining medical imaging and patient data, machine learning algorithms may also forecast a patient's risk of contracting certain illnesses or reacting to particular therapies. Clinicians are able to make better judgments about treatment strategies, resource allocation, and preventative care because of its predictive capacity [1 - 5].

However, there are a number of obstacles to the broad use of ML in medical imaging. The need for high-quality data to train these algorithms is a major problem. A lack of enough data may restrict the creation and functionality of ML models since medical imaging data is often sensitive and challenging to acquire. Resolving biases in the data used to train the algorithms is another difficulty. Careful consideration must be given to data selection and algorithm design since inaccurate representation of varied patient groups in the data may lead to biased or untrustworthy results. In spite of these obstacles, machine learning has enormous potential for medical imaging. By improving patient care, providing more precise diagnoses, and permitting better treatment options, it has the potential to revolutionise the sector. This chapter goes over the many kinds of machine learning algorithms that are used in medical imaging, as well as their benefits and drawbacks. We also look at some of the possible uses of machine learning in medical imaging, including picture segmentation, image registration, diagnosis, and CAD.

The field of dentistry known as endodontics focuses on treating the tissues and dental pulp that surround a tooth's root. The preservation of natural teeth depends on this specialty. Deep learning has enormous potential for enhancing diagnostic precision and detecting problems that may not be compatible with conventional clinical methods in the field of endodontics. Deep learning techniques such as Convolutional Neural Networks (CNNs) have greatly improved endodontic diagnostics by improving the detection of anatomical anomalies such as periapical lesions and taurodontism. To improve the model's performance, the dental radiograph dataset utilised in this chapter was pre-processed and CNN-optimized. By incorporating deep learning into endodontic processes, trends in imaging data may be better identified, resulting in more accurate treatments. The chapter also covers issues including algorithmic bias, data quality, and the significance of clinical correlation. Important issues like patient privacy and AI system openness are also addressed. In the end, cooperation across many disciplines will be necessary to develop deep learning in endodontics *via* research and the translation of clinical applications, which will eventually help dental patients [6 - 10].

Pneumonia is a common illness that mostly affects children and the elderly, and greatly increases morbidity and death globally. Conventional diagnostic techniques, such as clinical exams and simple chest radiography, have drawbacks and can result in incorrect diagnoses. As a result, using more sophisticated methods is crucial. An overview of deep learning-based object identification methods, namely Convolutional Neural Networks (CNNs), for the diagnosis of pneumonia from chest X-ray images is given in this chapter. By addressing issues including inconsistent picture quality, cryptic illness presentations, and overlapping symptoms with other lung disorders, these techniques enable accurate localisation of pneumonia-affected areas.

The medical imaging dataset, data preparation procedures, and model architectures—such as CNN, R-CNN, and YOLO—are covered in this chapter. It also investigates the use of VGG19 in transfer learning to improve pneumonia diagnosis rates. Metrics including accuracy, precision, recall, and mean Average Precision (mAP) are used to assess the performance of the model. Even with encouraging outcomes, there are still issues to be resolved, such as enhancing model interpretability, resolving ethical issues, and generalising models across various imaging sources. In order to promote the wider use of AI-driven pneumonia diagnosis in medical imaging, future developments may concentrate on combining data from several imaging modalities, allowing real-time detection, and improving result interpretability.

If misdiagnosed and untreated, sleep apnoea, a common sleep disease marked by frequent breathing pauses during sleep, may pose major health concerns. The

CHAPTER 2

Detection of Endodontic Anomalies through Advanced Deep Learning Techniques

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Abstract: Endodontics is one of the branches of dentistry that deals with the treatment of dental pulp and tissues in the area around the root of a tooth; this branch is very significant in maintaining natural teeth. The implementation of deep learning in endodontics has the potential to increase the effectiveness of diagnoses and the identification of problems in clinical approaches that might not adhere to the standard. Convolutional Neural Networks (CNNs), a type of deep learning, have revolutionized endodontic diagnostics by improving the accuracy of recognizing anatomical anomalies such as taurodontism and periapical lesions. In this chapter, the dataset of dental radiographs used in this work was pre-processed and enhanced using CNNs in order to maximize model performance. The application of deep learning in the endodontic workstream improves the pattern recognition of imaging data and, therefore, provides accurate treatment. Moreover, issues of data quality, algorithm bias, and clinical correlation are explored, along with important concerns of patient privacy and the built-in transparency of the AI systems. Therefore, the future of deep learning endodontics relies on collaborations across various disciplines in order to progress the field *via* research and translation of clinical applications to ultimately benefit dental patients.

Keywords: Apical Lesions, Artificial Intelligence, Cone Beam Computed Tomography (CBCT), Convolutional Neural Networks (CNNs), Data augmentation, Deep learning, Diagnostic accuracy, Endodontics, Image analysis, Missed canals, Model interpretability, Periapical radiographs.

INTRODUCTION

Endodontics is a specialized branch of dentistry focused on the treatment of the dental pulp and the tissues surrounding the root of a tooth. This field is highly

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significant in preserving natural teeth. One of the most popular endodontic treatments is root canal therapy, which is frequently used to treat infections or damage to the dental pulp. Despite the fact that the two terms are sometimes used interchangeably, endodontic treatment includes more than only root canal therapy. The dentist must safeguard the pulp whenever they perform any restorative dental procedures. Endodontics is the term for the whole pulp treatment process [1]. Endodontic treatments, like the other branches of dentistry, have been improved with the development of medical imaging and clinical practices; however, there are still some issues related to them. Misdiagnosis, in which the clinician may fail to or misinterpret diagnostic information; anatomical inconsistencies, which mean that the clinician may encounter different morphological features in the root canals of different teeth; and failed treatments, which are due to inadequate cleansing or sealing of the root canal system. These issues can cause discomfort to the patient by having unresolved dental problems, which also causes procedural inefficiencies that will require treatment more than once, leading to increased health costs and an elongated recovery time for the patient.

Background of Endodontics

All around the world, dental illnesses are common. The 2017 Global Burden of Disease report estimates that untreated dental illnesses, such as severe periodontal disease, unmanaged caries, edentulism, and severe toothache (with just one to nine remaining teeth), affect over 3.5 billion people globally [2]. Historically, surgical endodontics has been considered a last-resort procedure because of its poor results, primarily from material and technical restrictions. With improved visualization, more advanced materials, and more sophisticated techniques, success rates have increased, making endodontic microsurgery a worthwhile therapeutic choice for some patients. These developments do not, however, replace expertise in endodontic evaluation and treatment planning, which can frequently present difficulties. Numerous instruments are available to evaluate periodontal and pulpal health as well as check for fractures [3]. The predictability of treatments and the accuracy of diagnosis in endodontics have been advanced by the enhanced usage of some modern imaging systems, such as CBCT, microscope, and micro-CT. Cone-Beam Computed Tomography (CBCT) is a radiographic imaging technology that provides accurate and superior volumetric information regarding the structures of the maxillofacial complex [4]. With the help of CBCT, endodontists are able to visualise relationships of the apices of the roots with other structures that cannot be visualised using conventional 2D radiography; they are able to visualise the anatomy of root canals, and to detect diseases in periapical regions. Likewise, improved visualisation of the morphology of the root canal system increases the accuracy of the procedures relative to the available improved vision microscopy. Surgical microscopes are

gaining common place in operating rooms as they produce an excellent view of the surgical area, high magnification, and variable levels of resolution [5]. The features include enhanced illumination and better visualization of small structures within the oral cavity for surgeons and other dental personnel. Compared to other approaches to magnification, it permits the surgeon to accomplish therapies with superior accuracy [6]. More recently, micro-CT has been applied in clinical and preclinical bone and dental research over the last two decades [7]. Micro-CT offers extremely high-resolution three-dimensional (3D) imaging, which enables a microscopic assessment of periapical structures, small abnormalities in the canal, and root canal morphology. Understanding the complexities of root canal systems requires an unparalleled precision in anatomy visualization, which this technology provides.

LITERATURE REVIEW

Deep learning methods have shown significant potential in diagnosing irregularities in endodontic applications. These techniques have been applied to various aspects of endodontic diagnosis and treatment planning, demonstrating high accuracy and efficiency. Inendodontics, deep learning models, particularly Convolutional Neural Networks (CNNs), have been successfully used for tasks such as detecting periapical lesions, analyzing root canal morphology, and predicting treatment outcomes [8]. These models have shown high accuracy in critical tasks like detecting radiolucent lesions and analyzing root canal morphology. AI methods have been used, for example, to analyse the anatomy of the root canal system, calculate working lengths, identify periapical diseases and root fractures, and forecast retreatment procedure success [9]. It is interesting to note that, despite deep learning's potential in endodontics, endodontists still lack a thorough understanding of machine learning and deep learning principles, which prevents AI from being fully applied in this sector [10]. This highlights the need for better education and training in AI technologies for dental professionals.

In conclusion, deep learning methods have demonstrated significant potential in diagnosing irregularities in endodontic applications. They offer diverse practical applications, from enhancing diagnosis and treatment planning to improving education and patient care [11]. However, challenges remain in terms of model interpretability, generalizability, and integration into clinical practice (Mohammad-Rahimi *et al.*, 2024). Future research should focus on addressing these limitations and facilitating the seamless integration of AI into endodontic workflows.

CHAPTER 3

Deep Learning-Based Object Detection for Pneumonia Detection in X-Ray Scans

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Abstract: Pneumonia is a critical respiratory condition that requires prompt and accurate diagnosis to ensure effective treatment. With the growing availability of medical imaging, particularly chest X-rays, there is an increasing interest in leveraging machine learning techniques for automated pneumonia detection. This chapter explores a novel object detection approach for identifying pneumonia in chest X-ray images. The proposed method combines advanced deep learning architectures, such as Convolutional Neural Networks (CNNs), with object detection algorithms to accurately localize and classify pneumonia-affected regions in X-ray scans. The model is trained on a comprehensive dataset of labeled X-ray images, ensuring robust performance across diverse patient demographics and varying image qualities. Experimental results demonstrate the effectiveness of the proposed approach, showing high accuracy and sensitivity in detecting pneumonia compared to traditional methods. This work contributes to the growing body of research aimed at integrating artificial intelligence into clinical practice, offering a potential tool for radiologists and healthcare professionals to enhance diagnostic accuracy and speed. Future directions include the refinement of detection algorithms and the expansion of the dataset to improve model generalization across different clinical settings.

Keywords: Chest x-ray images, Convolutional Neural Networks (CNNs), Deep learning, Object detection, Pneumonia detection.

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INTRODUCTION

Pneumonia is a severe respiratory illness that affects millions of people globally, contributing to high mortality rates, especially among children and the elderly [1]. The disease can be caused by various infectious agents, including bacteria, viruses, and fungi. Early and accurate diagnosis is crucial for effective treatment, reducing complications, and improving survival rates. Traditionally, chest X-rays have been the primary imaging modality used to diagnose pneumonia. However, manual interpretation of these images is time-consuming and subject to human error, leading to inconsistent diagnostic accuracy [2]. The advent of Artificial Intelligence (AI), particularly deep learning techniques, has opened new avenues in medical imaging. AI-powered diagnostic tools can assist radiologists by automating the detection of pneumonia, leading to faster and more reliable diagnosis. This chapter explores an innovative approach that integrates object detection algorithms with deep learning models to identify and classify pneumonia-affected regions in chest X-rays, offering significant potential for improving healthcare outcomes [3].

BACKGROUND AND LITERATURE REVIEW

Pneumonia is a severe respiratory infection that inflames the air sacs in one or both lungs, often causing them to fill with fluid or pus. This condition affects millions globally, with young children, the elderly, and immunocompromised individuals being at the highest risk [4]. Timely and accurate diagnosis is critical for effective treatment, as delays can lead to severe complications or even fatalities. Traditionally, chest X-rays have been the gold standard for diagnosing pneumonia, enabling healthcare professionals to observe key indicators such as lung inflammation, consolidation, and other abnormalities [5].

Despite their utility, the manual interpretation of chest X-rays by radiologists has significant limitations [6]. This process is time-intensive and prone to variability, with diagnoses often differing between radiologists due to differences in experience, fatigue, or workload. These challenges are exacerbated in settings with a high patient load or limited access to skilled professionals, where diagnostic delays can have severe consequences [7].

With advancements in Artificial Intelligence (AI), particularly deep learning, there is an increasing focus on automating the detection of pneumonia using chest X-rays. AI-powered diagnostic tools offer the potential to address the limitations of manual interpretation by providing faster, more accurate, and consistent results [8]. These systems leverage Convolutional Neural Networks (CNNs) to analyze imaging data and identify complex patterns indicative of pneumonia. Object de-

tection algorithms further enhance these systems by localizing pneumonia-affected regions, offering radiologists actionable insights [9].

Despite significant progress, there remains a need for further refinement of AI models to ensure robustness across diverse clinical settings [10]. Expanding datasets to include varied patient demographics and imaging conditions is crucial for improving model generalization. Moreover, the integration of advanced methods, such as transfer learning and federated learning, holds promise for addressing data scarcity and privacy concerns [11]. By exploring these avenues, AI-driven solutions can advance pneumonia detection, reducing diagnostic errors and improving patient outcomes globally. The rise of Artificial Intelligence (AI), specifically deep learning, offers a promising solution for automating the detection of pneumonia from chest X-ray images. Deep learning models, particularly Convolutional Neural Networks (CNNs), have been widely adopted for image classification tasks in various domains, including medical imaging. In this review, we explore the evolution of deep learning techniques for pneumonia detection, highlighting key survey papers that have shaped the field [12].

Medical Imaging and the Need for AI in Pneumonia Detection

Traditional methods for pneumonia detection rely heavily on the expertise of radiologists to interpret chest X-ray images. While effective, manual diagnosis comes with several limitations:

- Human Variability: Different radiologists may interpret the same X-ray image differently, leading to variability in diagnosis. This inconsistency can result in misdiagnoses or delayed treatment, particularly in borderline cases.
- Time Constraints: In areas with high patient volumes, radiologists may face time constraints that limit the thoroughness of their diagnoses. This is particularly problematic in low-resource settings where there is a shortage of trained radiologists.
- Fatigue and Error: Human error, often exacerbated by fatigue, can reduce the accuracy of diagnoses, especially when radiologists are working under stressful conditions.

AI-driven systems have the potential to address these challenges by automating the detection of pneumonia from chest X-ray images [13]. With deep learning models capable of learning complex patterns in imaging data, AI systems can assist radiologists by providing faster, more consistent, and potentially more accurate diagnoses.

CHAPTER 4

Detection of Sleep Apnea Using IoT Technologies

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Abstract: Sleep apnea, a common sleep disorder characterized by recurring interruptions in breathing during sleep, can lead to severe health risks if not diagnosed and treated promptly. Traditional diagnostic methods, such as polysomnography, are often complex and costly, limiting their widespread use. The incorporation of Internet of Things (IoT) technologies offers a promising alternative for continuous, non-invasive, and real-time monitoring of sleep apnea. This paper investigates the application of IoT-based systems for detecting sleep apnea by utilizing wearable devices, environmental sensors, and cloud-based analytics. Wearable devices such as smartwatches, chest straps, and smart rings continuously monitor physiological signals like heart rate and blood oxygen levels, while environmental sensors collect data on snoring and body movement. These data streams are wirelessly transmitted to a central hub or cloud platform, where advanced machine learning algorithms process and analyze the information to detect apnea episodes. This method improves early detection and diagnosis of sleep apnea, offering a convenient, scalable solution for long-term monitoring and management. The paper also addresses key challenges, including data privacy, system interoperability, and user adherence. The integration of IoT in sleep apnea detection presents significant potential for enhancing patient outcomes through timely diagnosis and personalized treatment plans.

Keywords: Advanced Machine Learning, Cloud storage, ECG signals, Internet of Things (IoT).

INTRODUCTION

Safe sleep is vital to preserving our quality of life and plays a significant role in mental health. Sleep apnea occurs when a patient's breathing repeatedly stops and

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starts due to upper airway obstruction for at least 10 seconds during sleep. These episodes of apnea often last 10 to 30 seconds and may occur hundreds of times in a single night. Sleep apnea can result in either complete (apnea) or partial (hypopnea) upper airway obstruction, with the most common type being Obstructive Sleep Apnea (OSA). Numerous studies have explored automated sleep apnea detection and analysis using physiological signals [1, 2]. Among them, ECG-based approaches have shown promising results in capturing the cardiac irregularities associated with apneic events [3, 4].

OSA can lead to excessive daytime sleepiness (hypersomnia), mood swings, memory loss, cardiovascular diseases, and other serious health conditions [5, 6]. Polysomnography (PSG) is considered the gold standard for diagnosing sleep apnea, as it records multiple physiological parameters, including muscle tone (EMG), electrocardiogram (ECG), eye movements (EOG), and electroencephalogram (EEG), during various stages of sleep [7 - 14]. However, PSG involves at least 12 channels and is expensive due to complex electrophysiological data acquisition and interpretation, making it impractical for large-scale or home-based screening [15, 16].

Recent studies have focused on using fewer physiological signals, such as ECG, EEG, peripheral oxygen saturation (SpO_2), or nasal airflow, to detect apnea episodes efficiently [17, 18]. In particular, Heart Rate Variability (HRV) extracted from ECG signals provides valuable insights into the autonomic nervous system and helps identify breathing irregularities during apneic events [19 - 22].

The global prevalence of sleep apnea is significant, affecting about 4% of men and 2% of women, and is recognized as a major public health concern [23, 24]. Untreated OSA is associated with adverse outcomes such as hypertension, cardiovascular disease, daytime fatigue, and impaired cognitive function [25, 26]. Although PSG remains the clinical gold standard, its limitations necessitate alternative, cost-effective, and portable diagnostic systems.

With the growing adoption of Internet of Things (IoT) technologies in healthcare, there is a unique opportunity to leverage these innovations for continuous and non-invasive sleep apnea monitoring. IoT-enabled wearable devices can facilitate real-time data collection and cloud-based analysis, enabling timely diagnosis and intervention even in remote or underserved regions. Moreover, the integration of machine learning algorithms enhances the accuracy of apnea detection by processing large datasets collected from various sensors [27 - 30].

By exploring IoT-based and machine learning-driven sleep apnea detection systems, this research aims to provide a scalable and affordable solution that can improve early diagnosis, patient outcomes, and personalized treatment plans.

Addressing challenges such as data privacy, system interoperability, and user adherence will ensure that these emerging technologies are both practical and effective in real-world healthcare applications.

LITERATURE REVIEW

Obstructive Sleep Apnea (OSA) is a widespread condition characterized by intermittent upper airway obstruction during sleep, leading to disrupted breathing patterns. Early and accurate detection of OSA is crucial for preventing long-term cardiovascular and metabolic complications, and numerous diagnostic methods have been explored over the years.

Traditional diagnostic approaches such as polysomnography (PSG) have long been the gold standard for sleep apnea diagnosis. However, due to its high cost and resource-intensive nature, alternative methods have been proposed to provide more accessible and cost-effective solutions. Electrocardiogram (ECG)-based detection has emerged as a promising approach for sleep apnea monitoring. Several studies have utilized features extracted from ECG signals for the classification of apnea and normal states. For example, Nguyen *et al.* proposed an online sleep apnea detection method based on Recurrence Quantification Analysis (RQA) [1 - 3], demonstrating its potential for real-time monitoring. Similarly, Mendez *et al.* applied autoregressive models to single-lead ECG signals for OSA screening, further supporting ECG as a viable tool for sleep apnea detection [4].

Machine learning techniques have significantly advanced the accuracy of sleep apnea detection from ECG signals. Sharma *et al.* provided a comprehensive review of various machine learning models employed in ECG-based sleep apnea detection, emphasizing the importance of feature extraction techniques and classifier selection [5, 6]. Wavelet-based methods have also been shown to be effective, with Sharma *et al.* proposing a wavelet-based feature extraction method for improved detection accuracy [7]. Additionally, the use of higher-order spectra and HRV (Heart Rate Variability) data has demonstrated promising results, as explored by Atri and Mohebbi [8].

Moreover, approaches combining ECG-Derived Respiration (EDR) signals have gained traction in the detection of sleep apnea. Zarei and Asl explored the automatic classification of apnea and normal states using features extracted from HRV and EDR signals, showcasing their complementary roles in improving detection accuracy [9]. Further, the use of Empirical Mode Decomposition (EMD) and sliding trend approximate entropy has been demonstrated to effectively detect OSA from HRV signals [10].

CHAPTER 5

Investigation of Global Frameworks and Policies in Biotechnology Safety and Security Measures using KNN Clustering - Qualitative Study

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Abstract: The roles of biosecurity and biosafety in biotechnology ensure that public health, agriculture, and the environment are protected against risks from biological research and technological inventions. Biosecurity prevents misapplications of biological agents by avoiding bioterrorism, while biosafety measures ensure containment of the infectious agent from the laboratory to protect the workers, community, and the environment. AI technologies have huge potential to enhance biosecurity and biosafety through better identification, prevention, and control of biohazards. AI will aid in analyzing large data sets that support early warnings against outbreaks or other events related to bioterrorism. Monitoring genomic sequences is an important activity for scientists for better forecasting and the reduction of possible future threats. AI also enhances safety in laboratories through automation of routine procedures and enforcement of observance of safety protocols, with real-time monitoring and feedback. Notwithstanding its benefits, the implementation of AI faces challenges to accuracy, reliability, data privacy, and cybersecurity. Harmonious effort among AI developers, biotechnologists, ethicists, and framers of policy in setting the best practices for the responsible deployment of AI is therefore necessary. The COVID-19 pandemic underlined some of the weaknesses related to national capacities based on the requirement for dynamic biosecurity governance, comprehensive education, and training in the harmonization of regulations and structures of robust governance. Responsible AI can offer a stronger safety dimension to biotechnology and, with it, sustainability for the public's trust in scientific research and innovation.

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Keywords: AI-driven risk assessment, Biohazard management, Biotech trust initiative, Bioterrorism prevention, Laboratory automation.

INTRODUCTION

Biosafety and biosecurity form the two biggest elements of biotechnology, in the sense of protecting public health, agriculture, and the environment from risks deriving from biological research and innovation. Generally, biosafety primarily prevents exposure through strict rules in the laboratories, protective gear, and other measures of containment. Together, they decrease risks as they help in observing the international standards, which are the Cartagena Protocol and the WHO laboratory biosafety standards [1]. It offers them international standards for safe and secure practice. However, along with the development of biotechnology, there are challenges like emerging pathogens, dual-use concerns, and uneven capacities around the world that demand more enhanced practices of biosafety and biosecurity [2]. The ways through which AI takes on the challenge of safeguarding and responsibility in biotechnology are the early detection of threats, real-time monitoring, and predictive analytics of this transformative role artificially made in the improvement of these domains [3]. Issues on data privacy and algorithm reliability require cooperative approaches from policymakers, scientists, and technologists to ensure that biotechnology is safely and responsibly implemented by the global community in working through the challenges [4].

Biosecurity and biosafety are other important aspects of biotechnology that will help in ensuring the safe security of public health, agricultural production, and the environment from the impacts of harm that will occur due to biological research and biotechnological inventions. Biosecurity, as a term, is defined and implies the prevention of the misuse of biological agents and pathogens [5]. It is important to note that these pathogens can also be misused by causing damage through diseases or other forms of bioterrorism. This vision is achieved through adherence to strict guidelines and policies that govern the practice, intense monitoring, and preventive measures that allow the threat to be identified and thus averted or mitigated even before it reaches the crisis level [6]. On the other hand, it is concerned with the control of practices that attend to the handling and control of infectious agents and hazardous biological materials. The measures greatly reduce the chances of exposure to the said materials, hence protecting the researchers, the public, and the surroundings from exposure. Bit by bit, artificial intelligence is being applied to bring improvement in identification, precautionary measures, and biohazard controls in the field of biosecurity and biosafety [7].

AI technologies can be put to advancement in fields such as machine learning, deep learning, natural language processing, and computer vision that scout for

patterns and trends within vast data sets that might portend biosecurity and biosafety threats [8]. For example, AI will be able to scan worldwide health databases, social media, and scientific literature for the first signs of an outbreak or occurrence of events related to bioterrorism. Early detection of such signals will aid public health authorities and researchers to quickly make appropriate responses, hence preventing damage [9]. One of the predominant applications of Artificial Intelligence in biosecurity is the monitoring and analysis of genomic sequences.

It is going to allow the use of Artificial Intelligence to trace pathogen sequence changes and detect mutations that could potentially mean the appearance of new threats [10]. The developed capacity will enhance the capability of scientists to prevent and respond to biological threats more effectively. In addition, it may increase biosafety in laboratories through mechanization of routine activities, ensuring compliance with the requirements of safety and reducing the chance of human error [11]. AI can monitor laboratory environments, track biological material, and assess the risk of individual experiments. Through real-time feedback and alerts, AI supports a safe working environment and actively prevents accidents. In the field of biosecurity and biosafety, three typical ways to implement AI include data acquisition combined with processing, automation, and control with risk assessment and mitigation [12].

Data Acquisition and Processing: data from various sources are integrated, including genomic databases, epidemiologic reports, and environmental monitoring systems. Further, information is then fed into artificial intelligence algorithms for analysis in search of patterns and anomalies that may indicate biosecurity threats [13, 14]. For example, an AI algorithm might track an unusual increase in reports of a specific illness in one region or another, to which there is a need for further investigation [15]. AI easily brings information from various sources together to provide a more comprehensive view of biosecurity and biosafety risks, enabling well-informed decisions [16]. The next is automation and control. It will greatly improve biosafety within field laboratories [17].

Artificial intelligence is capable of automating the operation of equipment, monitoring conditions in the laboratory, and advancing surveillance. For example, AI-based robots can process hazardous material to diminish exposure for human workers [18]. Systems for automated monitoring can track conditions in the laboratory, such as temperature and humidity, on an ongoing basis, to ensure that they do not rise above or fall below the safety limits [19, 20]. It prevents human error by limiting the need for human intervention and thereby promoting a safer working environment [21, 22]. Finally, AI can be used to evaluate risks as well as

CHAPTER 6

Transforming Healthcare in India: The Role of e-Hospitals, Online Registration Systems, and AI

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Abstract: Artificial Intelligence (AI) is increasingly becoming a key player in India's healthcare sector, offering solutions that address some of the country's most pressing healthcare challenges, such as limited access to quality care, especially in rural areas, and a shortage of healthcare professionals. The preliminary study investigated the effects of various healthcare factors on infant mortality and life expectancy in India. For infant mortality, the coefficients for the number of doctors, medical institutions, and e-hospitals were negative but not statistically significant ($p > 0.2$). The ORS appointments had a small positive coefficient but lacked significance ($p = 0.696$). In contrast, life expectancy was positively influenced by ORS appointments ($\beta = 1.264$, $p = 0.020$), while other variables had non-significant effects ($p > 0.2$). This study highlights the significant role that digital and AI technologies play in shaping a more efficient, accessible, and patient-centric healthcare system in India.

Keywords: E-hospitals, Infant mortality and AI, Life expectancy, ORS.

INTRODUCTION

Globally, the adoption of AI in healthcare has shown remarkable potential in various domains, including diagnostic accuracy, personalized treatment, and operational efficiency [1]. AI applications, such as predictive analytics and medical imaging, have transformed traditional healthcare approaches by offering more precise and individualized care [2]. However, the successful implementation

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of these technologies requires overcoming significant challenges, such as data privacy concerns, infrastructure limitations, and resistance to technology adoption.

Artificial Intelligence (AI) is rapidly becoming a transformative force in healthcare systems worldwide, and India is no exception. As the country grapples with a diverse range of healthcare challenges—such as uneven access to quality care and a shortage of healthcare professionals—AI offers promising solutions to enhance the efficiency and effectiveness of healthcare delivery [3]. The integration of AI, alongside digital innovations like e-hospitals and Online Registration Systems (ORS), holds significant potential for improving health outcomes and optimizing resource management.

India's healthcare landscape is characterized by stark disparities between urban and rural areas, with rural regions often facing significant barriers to accessing quality care. Digital platforms, including e-hospitals and ORS, have emerged as pivotal tools in bridging this gap by providing remote access to healthcare services and streamlining appointment processes [4, 5]. These advancements reflect a broader trend towards digital health. Solutions that leverage Information and Communication Technology (ICT) to enhance service delivery and patient engagement.

In the Indian context, the integration of AI and digital health solutions has the potential to revolutionize healthcare delivery by addressing critical issues related to healthcare access and quality. The country's vast population and diverse healthcare needs necessitate a tailored approach that leverages digital innovations to improve patient outcomes and streamline healthcare operations [6]. For instance, the use of AI in managing healthcare resources and supporting clinical decision-making can lead to more efficient healthcare delivery and better health outcomes, particularly in underserved areas.

E-Hospital

An e-Hospital is a comprehensive, cloud-based Hospital Management Information System (HMIS) designed to streamline healthcare delivery by digitizing and integrating various hospital operations, including patient registration, admission, billing, and clinical data management. This system aims to enhance the quality and accessibility of healthcare services, improve operational efficiency, and facilitate seamless communication among patients, healthcare providers, and administrative staff. Developed under initiatives like the Ayushman Bharat Digital Mission, e-Hospital systems leverage advanced technologies to support teleconsultation, Electronic Health Records (EHR), and real-time data analytics for better health outcomes [7].

The e-Hospital system represents a significant transformation in the healthcare sector, focusing on reducing the administrative burden on healthcare facilities while improving patient experience. By incorporating a range of functionalities—from Online Registration Systems (ORS) to electronic billing and lab information systems—e-Hospital facilitates a patient-centered approach that allows for timely medical interventions and better resource management. This initiative not only improves operational workflows but also contributes to national health objectives by providing universal access to quality healthcare without financial hardship [7].

Online Registration System (ORS)

The Online Registration System (ORS) is a digital platform launched in July 2015, designed to facilitate seamless appointment scheduling and enhance patient services in hospitals. It enables patients to book appointments online, access lab reports, check blood availability, and make payments using their mobile devices, with integration capabilities for various Hospital Management Information Systems (HMIS).

The ORS serves as a user-friendly interface that empowers patients to efficiently manage their healthcare needs from the comfort of their homes. By allowing appointment bookings with or without Aadhaar authentication, and providing real-time access to lab results and blood availability, ORS significantly improves patient engagement and streamlines hospital operations. The system is integrated with the Ayushman Bharat Digital Mission (ABDM), enabling the creation of Ayushman Bharat Health Account (ABHA) IDs for patients. Additionally, the platform supports online payment options, making it easier for hospitals to collect registration fees and donations. With over 476 hospitals onboarded and millions of appointments scheduled, ORS exemplifies a significant advancement in digitizing healthcare services, ultimately contributing to a more efficient and accessible healthcare ecosystem [7].

LITERATURE REVIEW

The paper by Patnaik, S., and Pattnayak, P. (2021) discusses how Artificial Intelligence (AI), including machine learning, can be used in the Indian healthcare sector to improve access, quality, and affordability [8]. It highlights the use of AI and machine learning as a national strategy to enhance and empower the human population by addressing challenges in healthcare, education, and agriculture. The main finding emphasizes that India's AI implementation focuses on maximizing social impact and optimizing social goods rather than profit maximization.

CHAPTER 7

Critical Investigation and Impact of Artificial Intelligence in Healthcare

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Abstract: It was the COVID-19 pandemic that accelerated the adoption of telemedicine, and now artificial intelligence is going to be what really keeps the wave of transformation moving in health care. This chapter describes some of the different ways in which AI is likely to have an effect on healthcare: increasing productivity, diagnostic accuracy, and changing the very character of preventive care. Core to this discussion is Prenuvo, which applies AI to optimize whole-body MRI scans for the early detection of disease and preventative health screenings. With a core application of AI, Prenuvo tackles issues with the analysis of huge amounts of data, but also speeds up image acquisition and refines diagnostic accuracy to unparalleled levels of resolution that facilitate vital insights into conditions that might have otherwise gone unnoticed. The chapter further discusses other implications of AI in healthcare: its role in workplace wellness programs and potential to cut long-term healthcare costs. The case of Sesame Care shows how start-ups—increasingly those that did not found specifically on an AI delineation—turn to AI tools in order to increase provider productivity and boost the patient experience. The evolution mirrors part of a broader move toward the implementation of AI to enhance the efficiency and clarity of health-care services.

It also reviews the current obstacles and challenges for employers and health insurers looking to adopt AI technologies. It addresses legacy healthcare system challenges and discussions of responsible AI implementation. Employers must stay tuned to the evolution of AI and pilot programs best suited for desired outcomes that improve total benefit value and quality of care. This could definitely improve cost efficiency, benefit competitiveness, and quality employee wellbeing if AI is strategically implemented to fill the gaps in healthcare.

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Keywords: Artificial intelligence, COVID-19, Healthcare, MRI scan, Machine learning.

INTRODUCTION TO AI IN HEALTH CARE

In this constantly changing world of technology, Artificial Intelligence has moved from just being a mere imagination from the pages of science fiction into a reality that can dramatically change our lives [1]. Today, AI is no longer a futuristic concept but a part of our world—one which shapes the way we work, communicate, and decide. Rapidly becoming the bedrock of technology today is AI due to its ability to process massive volumes of data, recognize complex patterns, and draw rather informed conclusions. This stretches into machine learning, natural languages, vision by machines, and robotics—all areas that allow for systems performing tasks not only with remarkable efficiency but with accuracy previously thought unattainable.

In a health care domain filled with intractable and pressing challenges, AI is a source of optimism. Many health care systems around the world are grappling to optimize the 'quadruple aim': improved population health, better experience of patient care, satisfaction among care providers, and curtailing the meteorically escalating costs [2]. This is a pursuit compounded by an ageing population, burgeoning chronic disease, and a relentless rise in health care expenses. Such pressures are not just incremental but transformative in what care looks like. The pandemic has increased these challenges and brought to sharp realization the systemic inefficiencies and deepened disparities in access to care. It has shown up the vulnerability of our healthcare systems and the sense of urgency about their transformation. AI should, in this respect, not be seen as just another tool, but as a key enabler of change. One of the powerful applications of AI has been the ability to conjoin real-world data with advanced analytics in order to transform care in both its effectiveness and in moving toward equity.

The greatest change in this has been cloud computing. Quite recently, cloud technology has made it possible to analyze huge data sets at speeds that were literally inconceivable at one point in time. Cloud computing offers a way to scale up and handle the massive health data volumes generated every day in a cost-effective way, surpassing the capacity of traditional on-site infrastructures. This change is facilitating the migration of AI systems from their experimental phase into live applications within healthcare, giving the computing muscle needed for further advanced data analysis and AI-driven insights Fig. (**1**). The emergent interplay between AI and cloud computing portends a new epoch for healthcare in which technology and data work in concert to optimize care delivery, improve outcomes, and streamline operations. And, as the inter-partnership between the

tech providers and healthcare organizations gives rise to an opportune environment for AI-driven innovations, the general public has numerous benefits to reap from this. The next chapter shall address how AI will be the answer to the most compelling challenges in health systems, the transformational power of cloud computing in meeting these challenges, and how these technologies are already remaking the future of healthcare. Through the exploration of these recent developments, it is our aim to provide a comprehensive understanding that AI is addressing the immediate needs of healthcare, geared towards a more efficient, fair, and effective health system in the world.

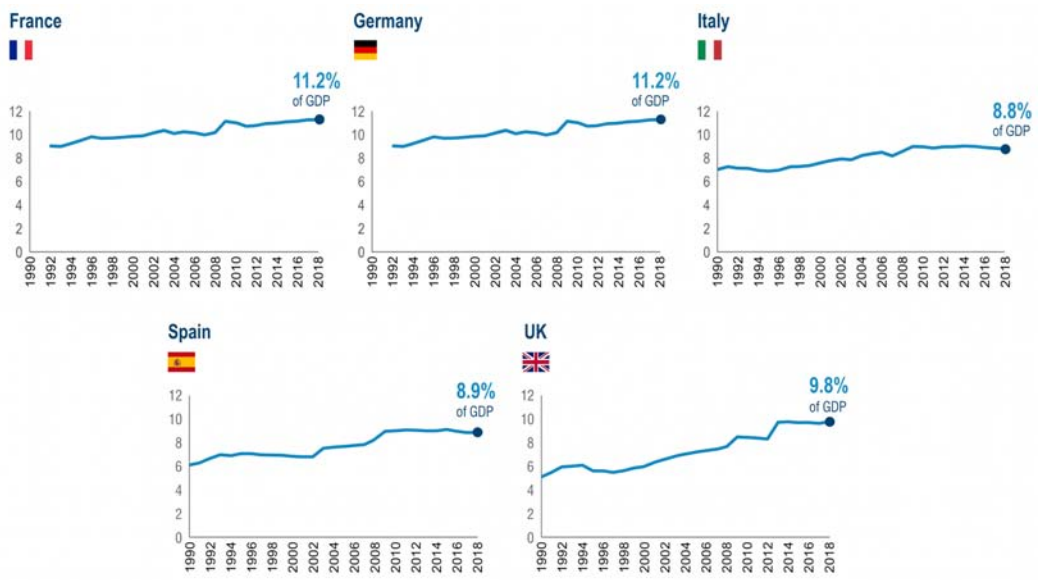


Fig. (1). Health care expenditure over the years [5].

IMPACT OF ARTIFICIAL INTELLIGENCE ON HEALTH CARE

The integration of technology and AI within the healthcare sector is a transformative opportunity toward old challenges facing either demand or supply in healthcare services.

As the healthcare landscape is evolving, burgeoning accessibility to different kinds of data, such as genomics, economic data, demographic information, clinical and phenotypic data, alongside rapid advancements in mobile technology, IoT, computing power, and data security, marks an important moment of convergence. It is at this juncture that this intersection of health and technology presents a potential paradigm shift in the delivery of care with AI-enhanced health systems. Artificial intelligence mainly deals with the science and engineering of making intelligent machines that could achieve cognition like humans, including

CHAPTER 8

AI-Driven Precision Revolutionizes Pneumonia Diagnosis with Advanced Object Detection in Chest X-Rays

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Abstract: Pneumonia is a major global health concern. Although treating patients with pneumonia requires a precise and consistent diagnosis, this has often proved to be difficult. It has been challenging to diagnose or identify pneumonia using conventional techniques without the use of software. The radiologist used to have to manually interpret the images, which could lead to irregularities and dishonest behavior. By successfully utilizing state-of-the-art object detection to identify pneumonia in X-ray pictures, our work seeks to overcome these drawbacks and improve the efficiency and accuracy of diagnosis. Chest X-ray pictures from people with and without pneumonia were gathered for this investigation using a sizable and extensive data collection. This was done to make checking easier—checking will be the most effective method. To respond right away, identify the situation. To find the best object identification algorithm, several reliable ones were examined, including R-CNN, Fast R-CNN, Convolutional Neural Networks (CNNs), and YOLO. The error propagation problems of the previously stated methodologies were addressed by the use of advanced object detection algorithms, which are among the most dependable and extensible ways to do this kind of work. CNN's feature maps, a powerful machine-learning technique in convolutional networks, are skilled at identifying a variety of elements in pictures. The goal of this work is to show how these algorithms may be applied to identify patterns in

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large amounts of diverse chest X-ray images, which could lead to better diagnosis and treatment of pneumonia. Removing the unwanted disparity in the images and the identification that follows, Pre-processing allows for the realization of crucial qualities. It is a more advanced phase in several machine learning algorithms. During the pre-processing phase, complicated and tailored procedures may be required for the object detection algorithms, which will be given in such a way that they may be used for chest X-ray detection.

Keywords: Chest X-ray, Convolutional neural networks, Diagnosis, Object detection, Pneumonia, Pre-processing.

INTRODUCTION

Bacterial pneumonia is the cause of pneumonia, a type of interstitial lung disease. According to a WHO report, pneumonia kills one in three people in India. A pneumonia detection device can be used to quickly diagnose pneumonia. The doctor can establish whether or not the patient has pneumonia with the use of X-ray imaging. Radiologists look for white patches in the lungs, which are a sign of an infection, when doing X-ray inspections. Accurate and timely pneumonia detection is essential for giving susceptible areas the right care and treatment. The most efficient way to identify them is by chest X-rays, which are evaluated for their ability to distinguish between abnormal and conventional chest X-rays. By examining chest x-ray pictures, Computer-Assisted Diagnostic (CAD) systems are crucial in the diagnosis of pneumonia [1]. Convolution neural networks [2] and other deep learning processes may be used to extract pertinent characteristics from photos for image classification applications [3]. Due to its substantial influence on worldwide morbidity and death rates, pneumonia remains a serious public health problem. According to the World Health Organisation, pneumonia is a major cause of death, especially for young people and the elderly. Effective intervention depends on a timely and correct diagnosis, but traditional diagnostic techniques are limited by their very nature: they need a lot of resources, take a long time, and are highly dependent on an abundance of specialised radiological knowledge.

Since computer vision offers solutions for a variety of problems that impact people in the twenty-first century, it should not be surprising that it is a significant field of Artificial Intelligence (AI) application. Particularly among the computer vision technologies that have continuously shown promise is the use of AI for medical picture identification. With over 4 million fatalities each year, pneumonia is one of the primary causes of mortality. There are several variations of pneumonia; it can be bacterial, fungal, or viral, and each of these variations might belong to a different class. Chest X-rays (CXR) [4] and Computed Tomography (CT) scans are frequently used to detect pneumonia; CXR is the most widely used method since it is less expensive and available worldwide. The computer's rapid

speed and objective, repeatable judgement can help the human expert diagnose pneumonia because the signs of the disease can sometimes not be visible or legible to the human eye in X-ray photos. There are several computer-assisted techniques for diagnosing and categorising pneumonia. These diagnostic methods have advanced significantly since the COVID-19 epidemic. The following lists a few of the most current and effective fixes, most of which rely on deep learning and Convolutional Neural Networks (CNN) [3]. In order to diagnose viral pneumonia, Jain [5] used transfer learning and the network architectures VGG-16, VGG-19, Resnet50, and Inception-V3. They achieved 71-88% accuracy on 624 test photos.

METHODOLOGY

Key methodology steps in the application of object detection for pneumonia from X-rays include dataset preparation, choice of model, training, and evaluation. Deep learning models have received much attention recently for detecting pneumonia. These models can process large volumes of image data in order to extract meaningful features, establish patterns, and detect abnormalities associated with pneumonia. For instance, Rajpurkar's CheXNet model [1 - 7], which was built on a 121-layer DenseNet architecture, achieved extremely high accuracy in identifying pneumonia from X-ray pictures. Other works of a similar kind have established that such deep learning models can excel the traditional diagnostic approaches, mainly in terms of sensitivity and specificity.

Supervised Learning

A large percentage of people contract the viral illness pneumonia, particularly in underdeveloped and impoverished nations where there is a dearth of healthcare infrastructure and a high prevalence of pollution, crowded living arrangements, and unhygienic living environments. Pneumonia causes pericardial effusion, a disease in which fluid accumulates in the chest, which renders breathing difficult. Although it is a difficult step, early diagnosis of pneumonia is essential for accessing treatment services and improving survival chances. The successful creation of prediction models is facilitated by the artificial intelligence discipline of deep learning. There are several methods for identifying pneumonia, including pulse oximetry, CT scanning, and many more; nevertheless, X-ray tomography is the most often used method. Chest X-ray (CXR) analysis is a difficult process that is vulnerable to subjectivity. In order to identify and classify pneumonia, this work trains a Deep Learning (DL) model with VGG16 using two CXR picture datasets. The results of the study show that VGG16 with NN outperforms VGG16 without the Support Vector Machine (SVM). Similarly, the techniques VGG16 with K-Nearest Neighbour (KNN) support, VGG16 with Random Forest (RF)

CHAPTER 9

Pathways and Strategies for the Fourth Industrial Revolution in Manufacturing Technology

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Abstract: Industry 4.0, also known as the digitalization of production, is defined by the integration of cyber-physical systems, automated processes, and information interchange. Manufacturing firms worldwide are already implementing this practice since it is no longer just a future trend. By doing so, they may reap the advantages of enhanced performance, decreased inefficiencies, including reduced costs, all while enhancing flexibility. Implementing Industry 4.0 technologies that enable it constitutes a complex endeavour that gets considerably more difficult without a consistent methodology. Organizational structures in the industrial sector are expected to undergo substantial changes as a result of Industry 4.0, particularly in terms of their value proposition and the evolution of the production network, vendor base, and customer interfaces. Industry 4.0 encourages monitoring in real time, maintenance planning, and adaptable manufacturing. This ensures optimal performance as well as reduces waste with immediate feedback and improvements. There exist several manufacturing obstacles, such as Cybersecurity threats, labour shortages, inadequate skills, as well as the need for defined standards and compliance among varied systems. Deployment and the incorporation of Industry 4.0 techniques need to address these obstacles. The present article shows how Industry 4.0 techniques are being adopted in aerospace, automotive, and manufacturing sectors. The findings emphasize that the best practices help firms maximise Industry 4.0's potential, improving sustainability and competitiveness in the fast-changing industrial landscape.

Keywords: 3D modeling, Automation, Cloud computing, Cloud storage, Cyber-physical systems, Digitalization of production, Digitization, Economic systems, Industrial revolution, Industry 4.0, Manufacturing efficiency, Smart factories, Smart products, Sustainability, Virtualization.

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INTRODUCTION

A new industrial revolution, often known as Industry 4.0, is being propelled by the fast-paced advancement of technology in the areas of digitization, connection, and automation. Numerous research obstacles are anticipated as an outcome of anticipated substantial variations in the social and economic systems [1 - 3]. The premise that Industry 4.0 has key characteristics with earlier industrial revolutions is central to this expanding corpus of scholarship. However, there are still doubts about the features' existence due to factors including late macroeconomic data, examples of early deployment, and persistent technology uncertainty [4, 5].

Industry 4.0 is a program with the goal of improving manufacturing. The main pillars of Industry 4.0 are shown in Fig. (**1**). The goal here is to ensure that Germany continues to be the world leader in manufacturing machines and automobiles. At the 2011 Hannover fair, the core idea was unveiled. Integration of technological and commercial processes, digital mapping, virtualization, “smart” factories, and “smart” goods are all part of the “Industry 4.0” framework [6 - 8]. It finds ways to make money and ways to save money, in addition to using new technology and digitalization. Some estimates put the potential cost savings in manufacturing, logistics, and quality control at 10–30% in Industry 4.0 plants. Industry 4.0 relies on digital technology to gather and analyze data in real-time, which is then fed into the manufacturing system [9]. The cyber-physical system concept of Industry 4.0 became a reality with the advent of the IoT, cloud computing, big data, and analytics. The complex technological design of manufacturing systems at the heart of the Industry 4.0 paradigm is one of the main challenges of this new industrial stage. Therefore, research into the most effective ways to implement Industry 4.0 technology is continuing. Several studies have examined the effects of these technologies on business efficiency, and some have suggested models for their maturity [10 - 12]. The 4 fundamental principles of Industry 4.0 are depicted in Fig. (**2**).

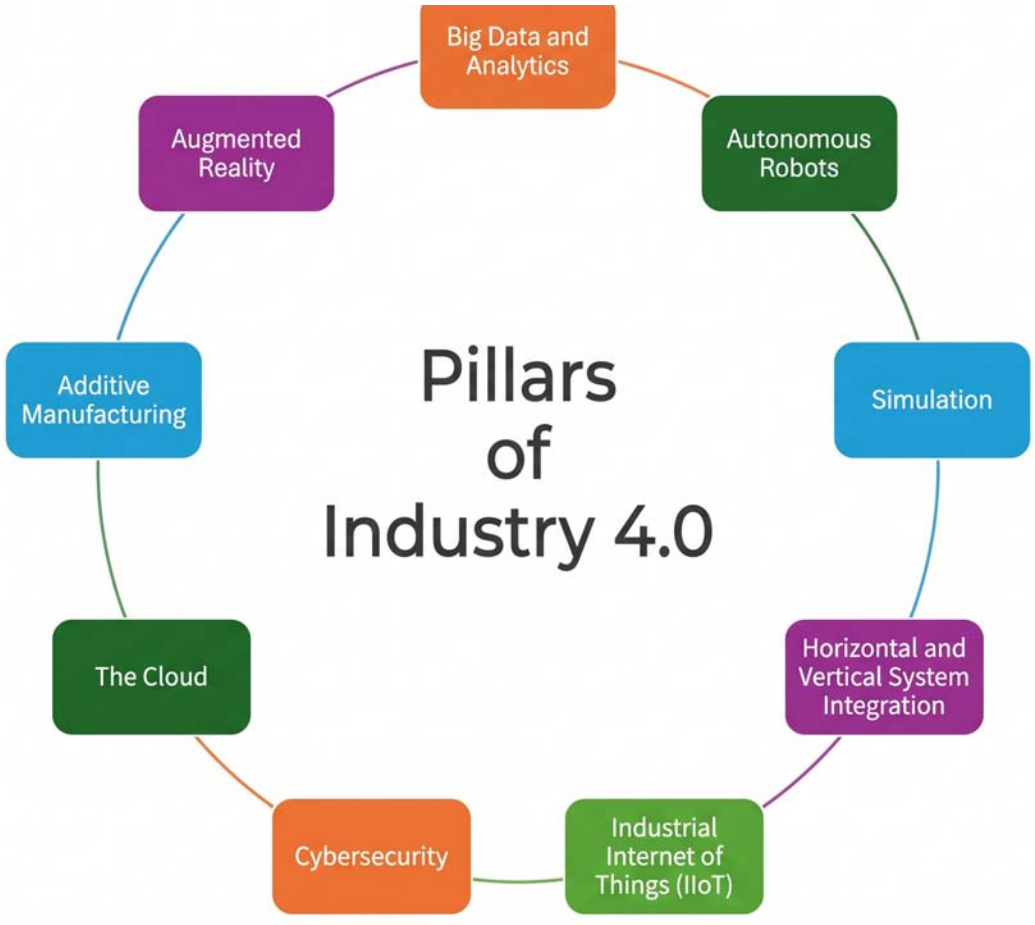


Fig. (1). Pillars of industry 4.0.

CHAPTER 10

Industrial Internet of Things for Manufacturing Techniques

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Abstract: Emerging technology developments and IoT applications in industrial systems are driving the evolution of Industrial Internet of Things (IIoT). The last twenty years have seen a worldwide shift toward data-driven, intelligence-driven production. In today's era of interconnected industrial systems, a smart production unit may be seen as a vast network of interconnected industrial components that can exchange data and coordinate their movements. The manufacturing sector has recently begun to concentrate on evaluating data from the whole production line, in addition to the usual focus on machine health and predictive maintenance. The Industrial Internet of Things (IIoT) is an alternate Internet of Things (IoT) concept that automates smart things to sense, gather, process, and communicate the events happening in industrial processes in real time. The principal objective of the Industrial Internet of Things (IIoT) is to attain superior operational efficiency, increased productivity, and improved management of industrial assets and processes *via* product customization, intelligent monitoring applications for manufacturing facilities and equipment health, as well as predictive and preventative maintenance of industrial machinery. This study demonstrates the many applications of IIoT technology, with a focus on the manufacturing industry. According to the results, the best practices assist businesses in making the most of IIoT, which boosts their sustainability and competitiveness in the dynamic industrial market.

Keywords: 3D modeling, Additive manufacturing, Cloud computing, Cloud storage, Cyber-physical systems, Digitization, Economic systems, Emerging technology, IIoT applications, Increased productivity, Industrial revolution, Industrial systems, Smart factories, Sustainability, Virtualization.

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INTRODUCTION

The Industrial Internet of Things (IIoT) represents the subsequent iteration of the Internet of Things (IoT) due to the distinctive nature of the industrial transformation it induces. Organizations seeking a competitive advantage in the present should only contemplate the potential advantages that IIoT may offer to logistics providers, workflows of the employee, product delivery, maintenance, and maintenance itself. Almost every aspect of a manufacturer's operations may be digitalized with the help of IIoT.

The main hazards associated with physical work and human mistakes can be mitigated by manufacturers by decreasing the necessity for manual operations and entry. The IIoT has the potential to lessen the risk of breaches of data and cyber-attacks, which are caused by mistakes made by humans. Many sensors gather data in a typical manufacturing site [1 - 4]. With the aid of the IIoT, factories can anticipate problems and fix them before they even happen, boosting efficiency and productivity. The flow of materials management, rapid identification and detection of problems in manufacturing, and optimization of machinery and equipment efficiency across every facility may be enhanced with the integration of site network data [5]. Smart factories, made possible by the expansion of the IIoT, have the potential to improve efficiency, transparency, and understanding in operations, therefore streamlining operations and altering commercial and operational processes in the manufacturing sector. The 4th industrial revolution is in its prime, and as a result, industry organizations are increasing their investments in IIoT. For IIoT to be a success, it is essential to simplify device deployment, connectivity, and administration. The ability to automate processes, remotely monitor operations, and make data-driven decisions is its primary value, as it boosts operational efficiency. Changes to manufacturing procedures may result from the installation of assets and machinery [6, 7].

IIoT systems can keep tabs on various industrial assets in real-time and provide a starting point for measuring their performance and capabilities. With this baseline and the data, the industry may be better prepared for any difficulties that may arise. Complete IIoT solutions use data from control and monitoring devices to build unified security systems that increase workplace safety [8, 9]. The IIoT enables vital operations in intelligent maintenance and operational management, which in turn unlock possibilities and propel digital advancements. A robust and interactive vision integrates different software and systems through the device-IIoT platform link. Through the integration of various data sources, the IIoT has been enhanced to provide staff with easy access to operational information and job instructions. Without any intervention from the user, the data is transmitted to the cloud, where software processes it and determines the next step, such as

notifying the user or automatically adjusting the sensors or devices. Wearable technology enabled by the Internet of Things allows for the evaluation of workers' health conditions as well as the monitoring of risky behaviors that might lead to injuries. Internet of Things (IoT) initiatives aim to address both the ongoing need to keep employees safe and any future risks that may arise [10, 11]. Events may be tracked all the way through a supply chain with the help of IIoT apps. These systems monitor stock levels on a worldwide scale and notify users of significant discrepancies. Managers have access to real-time inventory insight across all channels and receive precise estimates of available materials, WIP, and when new supplies will arrive. Optimal delivery and minimal cost-sharing along the value chain are the end results of this. The IIoT covers a wide variety of interrelated projects inside as well as outside of the facility [12 - 15]. Wearables, augmented reality on the floor, automated quality control systems, remote PC control, and full intelligent manufacturing solutions are all part of many IoT-based control and manufacturing initiatives. This encompasses a wide range of activities, such as managing distant industrial operations like petroleum refineries, controlling connected machinery remotely, and monitoring or controlling equipment [16]. Through IIoT efforts, manufacturers get a deeper comprehension of how their manufacturing lines and businesses function. As 5G networks become more commonplace and sensors shrink in size and cost, IIoT interest is certain to rise. For the time being, at least, it will probably pave the way for major players to fully digitally turn traditional processing into a digital factory. Industries requiring both high-quality products and quick development can benefit from IIoT. It explains a web-connected network of interconnected objects, such as computers and electrical devices, and provides critical support to manufacturing firms with similar needs [17, 18]. This allows for less invasive data exchange and consumption.

UNDERSTANDING THE IIOT CONCEPT

The phrase “Industrial Internet of Things” describes a digital revolution that is taking place in the industrial sectors. It links vital assets, sophisticated analytics (both predictive and prescriptive), and contemporary industrial workers. The term refers to a system that combines a network of interconnected industrial equipment with communications technology to provide unprecedented levels of monitoring, data collection, analysis, and sharing. Businesses in the industrial sector can utilize these findings to make more informed decisions in less time [19 - 21]. The IIoT streamlines production and operations by connecting smart sensors and actuators. It takes advantage of the data produced by “dumb machines” in manufacturing environments over an extended period of time through the use of smart machine capacities and analytics in real time. As stated in the IIoT guiding principle, smart machines outperform humans in two key areas: real-time data

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