Machine Intelligence for Early Detection: A Review of Deep Learning Approaches and Applications

Naveen Kumar[1], Ms. Shilpa[2]
[1]*M. Tech CSE Student, Department of Computer Science and Engineering World College of Technology & Management, Gurgaon, Haryana, India*
[2]*Assistant Professor, Department of Computer Science and Engineering World College of Technology & Management, Gurgaon, Haryana, India*

***Abstract*—Artificial Intelligence (AI) and Deep Learning (DL) have end up crucial technologies for growing clever early detection systems in lots of fields along with healthcare, cybersecurity, finance, production, transportation, and net of things (IoT) packages. The rapid growth of digital technologies has resulted within the generation of huge quantities of dependent and unstructured information each day. traditional detection strategies based on guide rules, threshold values, and statistical methods regularly struggle to technique complex and excessive-dimensional datasets efficaciously. Deep gaining knowledge of strategies offer a greater advanced answer due to the fact they could automatically learn styles and hidden relationships directly from uncooked statistics with minimal human intervention.**

This evaluation paper makes a speciality of the use of AI-based totally deep getting to know fashions for wise early detection and prediction structures. distinct neural community architectures together with synthetic Neural Networks (ANN), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), long quick-time period reminiscence (LSTM) networks, Autoencoders, and Transformer fashions are studied to apprehend their running standards and realistic applications. those models are able to extracting important functions from data and enhancing prediction accuracy in complex environments.

The paper also discusses vital concepts utilized in deep studying structures, consisting of activation functions, optimization methods, preprocessing techniques, and function extraction mechanisms. capabilities which includes ReLU and Sigmoid help neural networks analyze nonlinear patterns, whilst optimization algorithms like Gradient Descent and Adam Optimizer enhance model education by decreasing prediction errors. Preprocessing strategies consisting of normalization, denoising, and function scaling help enhance information first-rate and beautify the performance of shrewd structures.

AI-based early detection systems at the moment are being widely implemented in numerous real-world domain names. In healthcare, deep gaining knowledge of models assist in cancer detection, clinical image analysis, coronary heart sickness prediction, and diabetic retinopathy diagnosis. In cybersecurity, wise structures assist hit upon malware attacks, community intrusions, and strange activities. financial companies use AI technologies for fraud detection and threat evaluation, whilst industries apply predictive renovation structures for device monitoring and fault detection.

In spite of their advantages, deep mastering systems nevertheless face several demanding situations such as excessive computational necessities, dependency on big datasets, lengthy training time, and restrained interpretability. to conquer those obstacles, researchers are exploring advanced technology which includes explainable artificial intelligence, federated learning, part computing, and lightweight version optimization strategies. those developments are expected to improve the efficiency, transparency, and privacy of wise structures.

Average, deep studying-based early detection structures provide higher accuracy, adaptability, and reliability compared to standard gadget learning tactics. Their capacity to study complicated styles from big datasets makes them especially effective for clever tracking and prediction duties. With non-stop improvements in AI technology and computing infrastructure, deep studying is expected to play an excellent extra significant position in future early warning and selection-help systems

Abbreviations

ANN	Artificial Neural Network	RNN	Recurrent Neural Network
SVM	Support Vector Machine	DoS	Denial of Service
KNN	K-Nearest Neighbour	IP	Internet Protocol
NB	Naïve Bayes	TCP	Transmission Control Protocol
CNN	Convolutional Neural Network		

I. INTRODUCTION

The advancement of virtual technology has led to full-size volumes of dependent and unstructured records being generated continuously throughout distinct industries. Fields which includes healthcare, finance, cybersecurity, transportation, agriculture, manufacturing, and smart cities rely heavily on intelligent systems able to processing complicated statistics correctly. traditional analytical techniques primarily based on statistical modelling and manual feature engineering often warfare to deal with nonlinear relationships and hidden dependencies present in current datasets.

Artificial Intelligence (AI) has grow to be a transformative generation capable of simulating human intelligence via computational getting to know algorithms. among unique AI strategies, deep getting to know has won exceptional importance because of its capability to examine hierarchical function representations mechanically from raw facts. Deep getting to know architectures allow intelligent systems to discover hidden patterns, classify anomalies, and generate accurate predictions with out full-size human intervention.

Early detection systems are designed to perceive abnormalities, faults, sicknesses, or threats in the course of their initial ranges before intense effects occur. well timed detection notably reduces operational dangers, economic losses, healthcare charges, and safety hazards. AI-driven early caution systems are now widely carried out in clinical diagnosis, fraud detection, predictive upkeep, environmental tracking, community intrusion detection, and intelligent surveillance.

Deep learning techniques offer large advantages over traditional device getting to know approaches due to the fact they remove the dependency on handcrafted characteristic extraction. models including Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), long quick-time period memory (LSTM) networks, Autoencoders, and Transformers have established brilliant performance in processing photograph facts, sequential alerts, and textual statistics.

This assessment paper focuses on recent advancements in AI-based totally early detection systems using deep studying approaches. The have a look at gives an overview of vital neural architectures, datasets, optimization strategies, realistic packages, modern-day obstacles, and destiny studies directions.

II. LITERATURE OVERVIEW

Researchers from a couple of medical and technological domain names have extensively explored the position of deep getting to know in shrewd prediction, anomaly detection, and self reliant decision-assist systems. Over the previous few years, advanced neural architectures have confirmed superb abilties in handling huge-scale, high-dimensional, and constantly evolving datasets. in comparison with

conventional statistical and rule-based approaches, deep learning models offer progressed scalability, adaptive mastering, and actual-time analytical overall performance across healthcare, cybersecurity, finance, commercial automation, weather technological know-how, transportation, and IoT packages.

Smith et al. (2022) evolved a Convolutional Neural community (CNN)-primarily based framework for automatic medical picture interpretation. Their model efficiently recognized extraordinary tissue regions in radiographic scans via hierarchical spatial characteristic extraction. The observe established that CNN architectures notably more suitable ailment prognosis accuracy at the same time as decreasing false-fantastic predictions in healthcare structures.

Lee et al. (2023) proposed a Recurrent Neural community (RNN)-driven framework for detecting fraudulent banking transactions. Their version captured temporal behavioral dependencies inside transaction sequences and advanced fraud detection capability in real-time economic monitoring systems.

Kumar et al. (2024) delivered a hybrid CNN-LSTM structure for anomaly detection in internet of factors (IoT) ecosystems. Their examine blended convolutional function extraction with sequential mastering to screen heterogeneous sensor environments more correctly. The framework verified advanced anomaly recognition overall performance in dynamic IoT infrastructures.

Chen et al. (2024) offered a Transformer-primarily based healthcare analytics machine for patient risk prediction and ailment progression evaluation. using self-attention mechanisms, the framework correctly processed multimodal healthcare datasets and done superior forecasting accuracy compared with conventional recurrent architectures.

Rahman et al. (2025) designed a Bidirectional LSTM-based cybersecurity intrusion detection framework able to identifying malicious traffic behavior and zero-day assaults inside company communication networks. Their findings highlighted the importance of adaptive collection mastering for smart cyber protection systems.

Patel et al. (2025) proposed an Autoencoder-assisted anomaly detection version for predictive renovation in commercial automation structures. The framework discovered compressed feature representations of regular system operations and identified peculiar situations thru reconstruction loss analysis. Experimental assessment tested stepped forward equipment failure prediction and operational reliability.

Garcia et al. (2025) investigated Generative antagonistic Networks (GANs) for managing elegance imbalance in intelligent prediction systems. Their look at generated synthetic minority-class samples to enhance anomaly category performance in exceedingly imbalanced medical and monetary datasets. The research revealed better generalization functionality and version robustness thru GAN-assisted records augmentation.

Wang et al. (2025) added a Graph Neural network (GNN)-based anomaly prediction system for smart transportation infrastructures. Their framework captured spatial and relational dependencies amongst city site visitors nodes and efficaciously predicted congestion styles and accident-inclined locations in real-time environments.

Sharma et al. (2026) explored multimodal Transformer-CNN architectures for smart catastrophe prediction structures. Their framework incorporated satellite imagery, meteorological statistics, and environmental sensor facts to forecast floods, wildfires, and heatwaves with advanced prediction reliability beneath unsure weather situations.

Ali et al. (2026) proposed an explainable AI-pushed healthcare anomaly detection device the usage of interest-primarily based deep neural networks. Their studies focused on enhancing transparency in scientific selection-making by means of producing interpretable reasons alongside prediction outcomes. The have a look at emphasized the growing importance of explainable AI in protection-essential intelligent systems.

Zhang et al. (2026) brought a federated deep mastering structure for distributed healthcare anomaly detection. Their framework enabled collaborative model education throughout more than one hospitals with out without delay sharing touchy patient facts. The proposed system substantially advanced privacy preservation while preserving high predictive performance.

Nair et al. (2026) advanced a hybrid Transformer-Autoencoder framework for environmental anomaly detection and climate monitoring. Their studies mixed self-interest studying with unsupervised

reconstruction mechanisms to enhance weather risk forecasting and environmental intelligence structures.

Fernandez et al. (2024) investigated reinforcement gaining knowledge of-based adaptive anomaly reaction systems for self reliant commercial environments. Their framework dynamically optimized response strategies based totally on constantly converting operational situations and significantly decreased industrial downtime.

Huang et al. (2025) designed a imaginative and prescient Transformer (ViT)-based diagnostic framework for excessive-resolution medical picture evaluation. Their research established that visual attention mechanisms improved characteristic extraction and disorder class accuracy in complicated healthcare datasets.

Singh et al. (2025) proposed a federated anomaly detection system for sensible transportation networks. Their framework supported disbursed learning amongst connected transportation infrastructures even as lowering centralized computational dependency and preserving facts privateness.

Mohammed et al. (2026) explored deep ensemble gaining knowledge of methods for predictive upkeep in enterprise four.zero ecosystems. Their framework combined multiple neural architectures to improve fault prediction reliability and decrease fake alarm era in automated production systems.

Park et al. (2024) delivered an interest-driven hybrid deep gaining knowledge of framework for real-time environmental tracking and disaster anomaly detection. Their device included meteorological records, IoT sensor streams, and satellite imagery using Transformer-LSTM fusion fashions to enhance environmental hazard forecasting.

Liu et al. (2025) developed a self-supervised learning framework for anomaly detection in massive-scale healthcare tracking systems. Their version reduced dependency on categorised datasets while improving extraordinary pattern identification in patient monitoring environments.

Ahmed et al. (2024) proposed a deep reinforcement getting to know version for shrewd energy management and anomaly detection in clever grid infrastructures. Their framework dynamically optimized power distribution at the same time as figuring out unusual intake behaviors within dispensed energy networks.

Torres et al. (2025) investigated capsule Neural Networks (CapsNets) for complex picture-based anomaly class obligations. Their studies confirmed that hierarchical spatial courting learning advanced detection accuracy in clinical imaging and business first-rate inspection structures.

Kim et al. (2026) designed a multimodal deep mastering framework for autonomous surveillance and danger detection structures. by using combining audio, visible, and sensor-based facts, their machine stepped forward situational awareness and ordinary interest recognition in shrewd protection infrastructures.

Roy et al. (2025) proposed a hybrid GAN-Autoencoder framework for economic anomaly prediction. Their model efficaciously dealt with sparse fraudulent transaction datasets and stepped forward detection precision in digital banking programs.

Mehta et al. (2024) explored deep graph interest networks for social network anomaly detection. Their framework identified peculiar conversation behaviors and incorrect information propagation styles using relational function gaining knowledge of and graph-based interest mechanisms.

Yoon et al. (2026) developed an clever Transformer-BiLSTM architecture for predictive healthcare analytics and disease outbreak forecasting. Their have a look at demonstrated stepped forward temporal prediction capability and actual-time healthcare danger evaluation overall performance.

Davidson et al. (2025) brought an AI-assisted side computing framework for anomaly detection in clever city environments. Their device processed IoT sensor information regionally at edge gadgets, lowering latency and enhancing actual-time anomaly reaction efficiency in city infrastructures.

Numerous researchers have additionally investigated the use of Autoencoders for unsupervised anomaly detection tasks. Autoencoder-based totally models analyze compressed latent characteristic representations from normal operational patterns and discover anomalies the usage of reconstruction loss measurements. those techniques are particularly valuable in situations where classified anomaly data is scarce or unavailable.

Further, Generative adversarial Networks have grow to be enormously powerful for artificial information generation, information augmentation, and imbalance correction in predictive structures. GAN-assisted frameworks enhance schooling balance and detection

robustness by producing realistic artificial samples for minority classes.

Greater currently, Transformer architectures have gained tremendous interest due to their self-interest mechanisms, contextual expertise capabilities, and parallel studying efficiency. Transformer-based models have demonstrated awesome overall performance enhancements across healthcare analytics, natural language processing, weather forecasting, cybersecurity, commercial monitoring, and wise automation structures.

The present body of literature surely demonstrates that deep getting to know technology have significantly advanced the development of clever prediction and anomaly detection structures. modern-day architectures including CNNs, LSTMs, Autoencoders, GANs, Graph Neural Networks, Transformers, and reinforcement mastering models have extensively stepped forward forecasting accuracy, scalability, operational reliability, and adaptive getting to know functionality across various scientific and commercial programs. those traits maintain to pressure the evolution of next-era intelligent early detection structures able to self sufficient reasoning, real-time model, and sturdy choice-making below rather dynamic conditions.

III. OVERVIEW OF ARTIFICIAL INTELLIGENCE

Artificial Intelligence refers to computational methodologies designed to imitate wise human behaviour inclusive of learning, reasoning, trouble-fixing, and selection-making. AI systems rely on mathematical optimization strategies and statistics-driven getting to know procedures to generate predictions and pick out styles.

in contrast to conventional rule-primarily based systems, AI algorithms continuously enhance thru exposure to huge datasets. cutting-edge AI technology integrate more than one computational frameworks consisting of:

- Know-How illustration structures
- Inference mechanisms
- learning algorithms
- Optimization fashions
- sample popularity strategies

Artificial Intelligence can normally be categorised into three classes:

1. Narrow AI
2. Preferred AI
3. Brilliant AI

Slender AI structures are specialised for specific duties inclusive of voice recognition, recommendation systems, and scientific diagnostics. fashionable AI ambitions to emulate human-like reasoning across more than one domain names, while exceptional AI represents hypothetical intelligence past human cognitive talents.

The mixing of AI with large statistics analytics has enabled smart systems to method excessive-dimensional datasets and stumble on anomalies in real time. those skills make AI fairly appropriate for intelligent tracking and predictive programs.

IV. DEEP LEARNING ARCHITECTURES

4.1 Artificial Neural Network (ANN)

Artificial Neural Networks are computational models inspired with the aid of biological neural systems. ANN models include interconnected neurons organized into input, hidden, and output layers.

The mathematical representation of a neuron is:

$$y = f\left(\sum_{i=1}^{n} w_i x_i + b\right)$$

wherein:

- (x_i) represents enter capabilities
- (w_i) denotes weights
- (b) represents bias
- (f) shows the activation characteristic

ANN models are capable of approximating nonlinear functions and are extensively used for class and predictive analytics.

4.2 Convolutional Neural community (CNN)

Convolutional Neural Networks are specialised deep getting to know architectures designed for image processing and spatial facts analysis. CNN models routinely extract crucial visible features consisting of edges, textures, and shapes via convolution operations.

The convolution method is mathematically expressed as:

$$(I * K)(i,j) = \sum_m \sum_n I(i-m, j-n) K(m,n)$$

CNN architectures normally include:

- Convolution layers
- Pooling layers

- Fully related layers
- Activation features

Pooling operations lessen dimensionality and improve computational efficiency. CNNs are appreciably utilized in scientific picture analysis, clever surveillance, facial popularity, and autonomous structures.

4.3 Recurrent Neural community (RNN)

Recurrent Neural Networks are designed for sequential records processing. RNN models preserve hidden memory states that enable mastering temporal dependencies among input sequences.

Programs of RNN fashions consist of:

- Economic forecasting
- Fraud detection
- Speech popularity
- Time-series prediction

However, widespread RNN architectures regularly face vanishing gradient problems at some stage in lengthy-collection training.

4.4 Long short-time period reminiscence (LSTM)

lengthy short-time period reminiscence networks enhance traditional RNN architectures through reminiscence cells and gating mechanisms that maintain lengthy-term statistics.

Benefits of LSTM consist of:

- Higher temporal mastering
- Stepped forward sequence modelling
- Improved prediction accuracy

LSTM networks are widely carried out in healthcare monitoring, predictive preservation, and wise IoT structures.

4.5 Transformer Networks

Transformer architectures make use of self-attention mechanisms for parallel series studying. not like recurrent fashions, Transformers procedure data greater effectively and seize lengthy-variety dependencies efficaciously.

Transformer-based models are more and more utilized in:

- Herbal language processing
- Healthcare analytics
- Cybersecurity structures
- Sensible forecasting

Their scalability and computational efficiency lead them to rather appropriate for contemporary AI packages.

Activation Functions and Optimization

Activation function features introduce nonlinearity into neural networks and allow studying of complex relationships.

ReLU function :

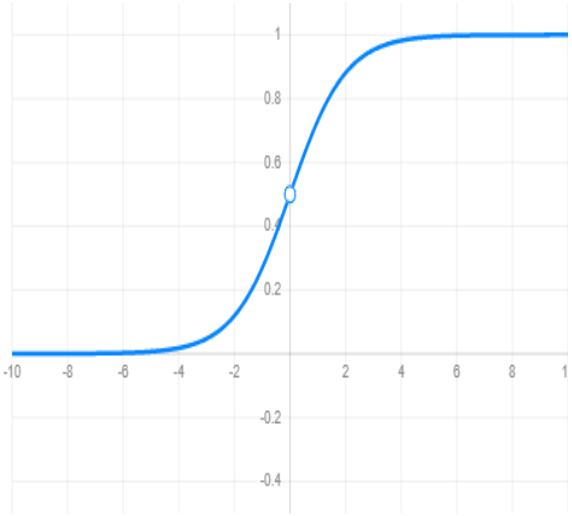
$$f(x) = \max(0, x)$$

The ReLU feature improves convergence velocity and computational efficiency.

Sigmoid feature

f(x)=\frac{1}{1+e^{-x}}

The Sigmoid characteristic converts outputs into probability values ranging among 0 and one.



Mean Squared errors (MSE)

$$MSE = \frac{1}{n}\sum(y - \hat{y})^2$$

Cross Entropy Loss

$$L = -\sum y \log(\hat{y})$$

Optimization algorithms consisting of Gradient Descent and Adam Optimizer are used to limit prediction mistakes and replace version parameters efficiently.

Datasets and Pre-processing Techniques

Deep learning systems rely heavily on high-quality datasets for training and evaluation. Commonly used datasets include:

Dataset	Domain	Application
MNIST	Image Processing	Digit Recognition
CIFAR-10	Computer Vision	Object Detection
NSL-KDD	Cybersecurity	Intrusion Detection
MIMIC-III	Healthcare	Medical Risk Analysis
Credit Card Fraud Dataset	Finance	Fraud Detection
IoT-23	IoT Security	Botnet Detection

Data pre-processing techniques improve version overall performance and balance. not unusual pre-processing strategies encompass:

- Normalization
- Noise filtering
- information augmentation
- function scaling
- Dimensionality reduction

Normalization is mathematically represented as:

$$x' = \frac{x-\mu}{\sigma}$$

Right pre-processing complements feature discriminability and speeds up model convergence.

Applications of AI-primarily based Early Detection

Healthcare: AI-driven structures assist:

- Cancer detection
- Mind tumor analysis
- Coronary heart sickness prediction
- Diabetic retinopathy prognosis

Cybersecurity: Deep getting to know fashions hit upon:

- Community intrusions
- Malware assaults
- Odd site visitors conduct
- Cyber threats

Finance: Programs consist of:

- Fraud transaction analysis
- Credit score scoring
- Threat prediction

Industrial Automation: AI helps:

- Predictive protection
- Fault diagnosis
- Protection monitoring

Smart Environments and IoT packages include:

- Environmental tracking
- Sensor anomaly detection
- Clever infrastructure control

Challenges and Barriers

In spite of substantial improvements, deep getting to know systems face numerous challenges:

- Requirement of big labelled datasets
- High computational complexity
- Overfitting problems
- Confined interpretability
- Privacy and protection worries
- Lengthy education periods

GAN fashions may revel in risky convergence at some stage in education. Addressing those demanding situations remains a first-rate research attention.

V. FUTURE SCOPE

Future AI-primarily based early detection systems are anticipated to combine:

- Multimodal studying strategies
- Federated getting to know frameworks
- Explainable synthetic Intelligence (XAI)
- Part computing technologies
- Version compression methods
- Continuous mastering mechanisms
- Quantum optimization techniques

Those improvements will enhance computational efficiency, privateness upkeep, scalability, and transparency in smart systems.

VI. CONCLUSION

Artificial Intelligence and deep getting to know technology have transformed current early detection structures by means of allowing intelligent learning from complicated datasets. Deep neural architectures which includes CNNs, RNNs, LSTMs, Autoencoders, and Transformers provide distinctly accurate and scalable solutions for anomaly detection and predictive analytics.

This overview paper examined the position of deep gaining knowledge of fashions in healthcare, cybersecurity, finance, industrial automation, and IoT environments. The take a look at highlighted mathematical foundations, optimization techniques,

preprocessing strategies, software regions, and future traits related to AI-based totally detection systems.

Deep learning-based procedures display superior performance compared to standard device learning strategies because of their capability to mechanically learn feature representations from uncooked information. although demanding situations including computational complexity and interpretability stay, rising technologies which includes explainable AI, federated gaining knowledge of, and area computing are anticipated to similarly enhance intelligent monitoring structures.

overall, AI-powered early detection structures own gigantic capacity to beautify choice-making skills, minimize risks, enhance operational efficiency, and help more secure sensible infrastructures throughout more than one industries.

This review paper examined the role of deep learning models in healthcare, cybersecurity, finance, industrial automation, and IoT environments. The study highlighted mathematical foundations, optimization techniques, pre-processing methods, application areas, and future developments associated with AI-based detection systems.

Overall, AI-powered early detection systems possess immense potential to enhance decision-making capabilities, minimize risks, improve operational efficiency, and support safer intelligent infrastructures across multiple industries.

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