CHAPTER 12
Integrating IoT Networks with Deep Learning

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ABSTRACT

The rising global population, along with the challenges faced by conventional agricultural practices, has intensified the demand for smart agricultural solutions. In modern agriculture, the integration of Internet of things and machine learning-deep learning has evolved as an irreplaceable force, particularly in the context of soil-less farming systems. This study aims to explore the potential of IoT and intelligent data-driven technologies in advancing smart and precise soil-less agriculture systems and the review commences by scrutinising the basic principles of IoT and its application in soil-less agriculture. It also emphasises the integration of diverse sensors for real-time data collection on dynamic environmental and plant parameters. The advantages of IoT and machine learning–deep learning in soil-less agriculture systems are comprehensively analysed, covering numerous applications. This study also recognises challenges, such as data security and privacy concerns, and interoperability concerns which must be addressed for wider adoption and sustainable growth. Overall, this review paper presents a comprehensive assessment of IoT and ML-DL in soil-less agriculture systems. It highlights the potential of these technologies in tackling the key challenges faced by modern soil-less agricultural systems. Ultimately, these advancements can contribute significantly towards a greener and sustainable future for agriculture.

Keywords: *global population, IoT and machine learning–deep learning, numerous applications etc.*

INTRODUCTION

In light of the pressing issues of a growing global population, ensuring food security, combating climate change and promoting environmental sustainability, the agricultural industry is confronted with a critical demand for inventive resolutions [1, 2]. The Earth's arable land is limited and demands the fixation of various challenges, namely soil degradation, water scarcity and urbanisation, through the development of innovative crop cultivation systems [3]. As urbanisation is skyrocketing, arable land becomes very scarce and conventional agricultural approaches are becoming impractical in the densely populated urban areas. Developing alternative systems that require limited land usage, soil, water and other resources that can be adopted in urban areas is vital for meeting the future food demand with limited resources. Soil-less agriculture has surfaced as a promising substitute for traditional soil-based farming, providing a plethora of benefits [4]. However, in order to fully unlock the true potential of soil-less agriculture and address the complex requirements of contemporary food production, it has become imperative to implement technological interventions. Over the past few years, agriculture has witnessed a remarkable convergence of agriculture and technology that gave rise to several ground-breaking solutions to agricultural problems.

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Soil-free farming techniques, including hydroponics [5], aeroponics [6], aquaponics [7], etc., have become highly popular as they provide optimal conditions for crop growth.

These methods entail cultivating crops in nutrient-rich solutions or inert media, where environmental factors such as temperature, relative humidity, light and nutrient required can be meticulously regulated. The regulated environment enables more accurate management of growth circumstances. This leads to better crop quality, improved yield, reduced pest attacks, and decreased resource wastage (Figure 1). The year-round cultivation of crops irrespective of weather patterns or seasonal constraints is made feasible through soil-less cultivation. This helps in improving food security and meeting the growing demand for fresh produce. This is critical in urban settings where access to locally sourced food is limited. In the present era, marked by swift technological progress, the integration of Information and Communication Technology (ICT) in agriculture is inducing a metamorphosis in the modus operandi of cultivation. This reduces the disparity between conventional farming techniques and cutting edge inventions [8-10]. The Internet of Things (IoT) plays a crucial role in the progression of precision agriculture, as it integrates various sensors, actuators and devices, helping real-time surveillance and data acquisition of environmental and plant parameters [11, 12].

The continual input received from sensors measuring factors, such as temperature, relative humidity, light intensity, etc., provides the stakeholders with data-driven decisions in nearly real-time. This enhances crop yield and quality [13]. Maintaining the ideal growing conditions through continuous monitoring and estimation of nutrient requirements, pH levels, temperature and humidity are critical in soil-less cultivation systems and this calls for the intervention of IoT-based solution [14]. The value of IoT in soil-less cultivation extends beyond the data collection, to data processing and decision-making, with sophisticated multi-modal data analysis and machine learning approaches, identifying patterns and generating valuable insights [15]. Even though IoT serves as the backbone of the automation system that connects sensors, the ML/DL-driven intelligent decision is also another central pillar of the system. Through ML algorithms, agricultural experts can gain significant insights from data. Further, it optimises resource management and making informed decisions to boost productivity and sustainability [16, 17]. These insights can be potentially used to optimise resource allocation, fine-tune environmental conditions and detect major issues such as pest-diseases outbreaks [18, 19]. This study aims to explore various applications, challenges, and opportunities in this field, ultimately providing researchers, practitioners, and policymakers with a comprehensive understanding of how IoT and ML-DL can promote sustainable and efficient crop production in soil-less agriculture.

As health awareness continues to grow in today’s society, more people are focusing on the effectiveness of their fitness training. However, due to the lack of professional guidance, many individuals perform exercises with improper form, leading to suboptimal results or injuries [1], [2]. Action recognition plays a crucial role in fitness applications by enabling automated monitoring and feedback. This technology ensures proper exercise form and reduces the risk of injuries. Therefore, the study of fitness action recognition systems has become a crucial topic. These systems utilize image analysis technology to monitor and identify users’ fitness actions in real-time, providing targeted feedback and suggestions to help users engage in more scientific and effective training.

Currently, researchers employ various methods to study fitness action recognition systems. Traditional approaches primarily rely on manually designed features and machine learning algorithms, such as Support Vector Machines (SVM) and Random Forests. Although these methods perform well in specific scenarios, they struggle with the complexity and diversity of fitness actions. With the advancement of deep learning technology, models based on Convolutional Neural Networks (CNN) [3], [4] and Recurrent Neural Networks (RNN) [5], [6] have become mainstream. These models can automatically extract high-level features and capture long-term dependencies in sequential data, showing outstanding performance in action recognition tasks. Moreover, the application of IoT and communication technologies allows fitness data to be transmitted and processed in real-time, providing immediate feedback and guidance, significantly enhancing the system’s practicality [7], [8].

Despite the progress made in this field, numerous challenges remain. First, the variations in individuals’ body types, exercise forms, and background environments significantly increase the complexity and uncertainty of action recognition. Second, the current fitness action recognition systems still need improvement in terms of real-time performance and accuracy, especially when handling complex multi-joint movements. Additionally, effectively utilizing multimodal data (such as images, depth information, and sensor data) for fusion and analysis remains an unsolved problem [3], [4], [9]. The integration of IoT and communication technologies with fitness action recognition systems can further enhance system performance and user experience.

To address these challenges, we propose the ResNet-TransFit network model, which integrates ResNet for image feature extraction, Transformer for processing time-series data, and transfer learning for efficiently adapting to new fitness movement data. Our approach aims to provide a more accurate, efficient, and scalable solution for real-time fitness monitoring.

ResNet (Residual Networks) assumes the role of image feature extraction in our model.ResNet effectively solves the problem of gradient vanishing and gradient explosion in deep neural networks by introducing residual connectivity, enabling the model to train deeper network structures to extract higher-level, more representative image features. This is crucial for recognizing complex fitness movements as it captures the details and variations of the movements. In IoT environments, these feature extraction capabilities allow motion data collected through smart devices to be processed efficiently for more accurate action recognition. The Transformer model processes time-series data through a self-attentive mechanism. Compared to traditional recurrent neural networks (e.g., LSTM), Transformer excels in capturing long-term dependencies and global features. It is able to process sequence data in parallel, which significantly improves computational efficiency and performs particularly well when dealing with long time sequences. In fitness action recognition, Transformer is able to effectively capture and understand the dynamic changes of continuous actions, improving the accuracy and real-time performance of action recognition. With the real-time data transmitted through the communication network, the system is able to continuously monitor the user's movement and provide instant feedback and guidance. In addition, transfer learning techniques are equally important in our model. Through migration learning, we are able to utilize ResNet models pre-trained on large-scale datasets (e.g., ImageNet) to fine-tune and quickly adapt to new fitness movement data. This not only reduces the training time of the model, but also dramatically improves the performance of the model on small sample datasets, thus increasing the generalization ability and robustness of the system. In conjunction with IoT devices, the pre-trained and fine-tuned models are able to operate efficiently in edge computing environments, providing real-time data processing and feedback.

ROLE OF DEEP LEARNING IN IOT

Artificial intelligence and the internet of things have the potential to completely transform today's busi nesses, economies, and other sectors. With the use of AI, the Internet of Things may build smart robots that can mimic human intelligence and aid in making decisions with little oversight. With its impressive accomplishments in areas (Bibri & Krogstie, 2019) such as image identification, information retrieval, voice recognition, natural language processing, indoor localization, physiological and psychological condition detection, etc., Deep Learning will play a crucial role in developing smarter IoT. Data science, which also encompasses fields like statistics and predictive modelling, relies heavily on deep learning. Data scientists who are entrusted with gathering, analysing, and interpreting massive volumes of data will find deep learning to be incredibly useful. To acquire knowledge, deep learning networks must first identify complex patterns within the information they are fed. Networks may establish several degrees of abstraction to describe the data by constructing computational models with numerous processing layers.

APPLICATION OF IOT

It depicts some of the numerous areas in which the Internet of Things has found use, includeing the "smart home," environmental monitoring, medical and healthcare, agriculture, transportation, manufacturing, infrastructure management, and so on.

SMART HOME

As an Internet of Things (IoT) application, smart homes automate our daily lives by linking our numerous appliances together through a central management system and their built-in sensors to ensure our safety and convenience. Smart home technology include things like televisions, light bulbs, security cameras, and home appliances It's no surprise that smart home automation is on the rise with the Internet of Things (IoT) and other ICTs. Intelligent home devices, such as Internet of Things and sensor systems, talk to one another across a network. These high-tech appliances allow their owners to get entry to a wide range of useful domestic services. By using voice commands or applications, the individual may control all smart gadgets in the home, including the TV, music, lighting, and more, while inside the house. Whether the user is away from home or not, they can still check in on their smart home gadgets and control or adjust settings as needed

ENVIROMENTAL MONITORING

In order to give accurate weather forecasts, sensors are employed by the Internet of Things' Environ ment Monitoring application to keep tabs on things like air, temperature, humidity, water, soil, fisheries, and forests. When it comes to ensuring the well-being of both humans and the planet, environmental monitoring is crucial. The quality of the environment can only be determined via constant observation of environmental factors

IoT technology is the most popular choice for many businesses and sectors. This includes the smart environmental monitoring sector. IoT refers to a framework and idea that is studied in relation to various things that may be linked together via wired and wireless connections, and that can communicate with one another and work together to provide novel services and solutions

MEDICAL AND HEALTHCARE

IoMT is rapidly becoming an essential part of modern healthcare. Through the collection and trans mission of data from a variety of sources to devices enabled by cloud storage, it provides intelligent healthcare services. Furthermore, it may be used to keep tabs on patients' vital signs in real time and send out alerts in the event of an emergency. Smart beds are one example of an IoT use in the medical and healthcare sec tors, where they may be used to monitor bed occupancy and detect when patients try to rise. Smart beds may modify their own firmness and pressure settings to ensure the user is comfortable In order to better care for their patients, smart medical devices collect and transmit patient data to remote servers. Transferring information to a cloud host securely and efficiently is challenging.

AGRICULTURE

IoT has enabled "smart farming," which helps farmers increase output by keeping tabs on water use and soil moisture levels in real time and automatically adjusting water distribution to match. The IoT plays a crucial role in farming operations. Smart IoT-based agriculture is a novel idea since IoT sensing items may provide information on the condition of crops. Smart irrigation, remote crop monitoring, a greenhouse monitoring and automation system, sensor-based precision agriculture, etc., are all areas where the Internet of Things has shown its worth in the agricultural sector. Agricultural automated systems, such as those for farm connection, smart environments, water resource management, measuring instruments, crop management, and so on, may benefit from its utilisation. Connected sensors may pool information and send it to a central hub for processing.

TRANSPORTATION

Communication, data processing, and control are all made possible by the Internet of Things' use in the transportation sector. The Internet of Things has several positive effects on the transportation industry, including the reduction of costs associated with product and person tracking and the enhancement of both

quality and safety. As a result, driving becomes more intelligent, and fleet management services that include real-time fuel use, GPS vehicle monitoring, and reduced costs boost productivity. Incorporating the concept of "smart" transportation and cars, the IoT is transforming the traditional social framework into a highly technological one. Even more so, modern cars are equipped with high-tech equipment that can detect the traffic jam and advise the driver on the best way to go around it. It's possible that this may help alleviate the city's traffic woes.
In addition, affordable smart devices for monitoring motor operations should be developed and integrated in various vehicle classes. The Internet of Things is very helpful for monitoring a vehicle's condition. There is obviously more work to be done before his approach can be used globally. In the meanwhile, IoT technologies may help by anticipating traffic jams and taking corrective measures. Therefore, it is in the public interest for a company that produces vehicles to include IoT technology into their products.

MANUFACTURING

Using real-time data gathered from machines, material trucks, and the environment, IoT allows for greater automation and productivity in the manufacturing sector. Based on this data, various programmes and algorithms may make judgments mechanically. Industrial IoT is helpful in production for energy management, productive maintenance, and supply chain management.

SMART CITY

IoT is at the heart of smart cities. Smart traffic lights, water metering, and smart building energy management systems are all important components of a smart city's water supply, traffic flow, and energy efficiency. In order to create a smart city, IoT is one of the most often used approaches, which has a smart automation capacity for generating and organising smart applications for intelligent communities. Sensors embedded in ordinary objects are connected to the internet through an IoT network, allowing them to n communicate and share data to benefit city people. Devices that connect with each other across a network or the Internet are referred to as IoT devices. In the Internet of Things, a device's integrated circuits, sensors, and algorithms regulate the device's behaviour. Using sensors, each thing gathers and communicates information about itself and its surroundings to other items and the central channel. IoT data storage and mtransmission is now a critical issue for any organisation looking to use IoT as a technology.

CONCLUSION

Integrating IoT networks with Deep Learning (DL) represents a paradigm shift in disaster management, moving from reactive responses to proactive, data-driven precision. The conclusion of this research typically centers on these three pillars: The Power of Real-Time Intelligence- The primary value lies in the synergy between hardware and "brains." While IoT provides the "nervous system" (sensors for vibrations, water levels, or heat), Deep Learning acts as the "cortex" that can process massive, noisy data streams in milliseconds. This combination significantly reduces False Alarm Rates (FAR) and increases the lead time for evacuations, potentially saving thousands of lives. Overcoming Data Latency via Edge Computing- A critical conclusion in recent papers is that cloud-only processing is insufficient during disasters when infrastructure fails. The integration must move toward Edge AI. By running DL models directly on IoT gateways or drones, the system maintains "situational awareness" even if the main internet backbone is destroyed, ensuring the survival of the monitoring network itself. Future Scalability and Interoperability- The research concludes that for these systems to be effective globally, they must move away from proprietary silos. The future depends on standardized protocols that allow a diverse array of sensors (from different manufacturers) to feed into a universal DL framework. This "plug-and-play" resilience is what will make AI-IoT systems viable for smart cities and rural disaster zones alike. The Bottom Line: Integrating IoT and DL isn't just an upgrade; it's the foundation for Autonomous Disaster Management, where systems can detect, analyze, and trigger life-saving actions without waiting for human intervention

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in time-critical moments. Would you like a summary of a specific 2025/2026 paper that demonstrates this integration in a real-world scenario, like flood or wildfire detection?

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