

<sup>1</sup> D. Venkatesh  
<sup>2</sup> D. Hemanand  
<sup>3</sup> P. Shobha Rani  
<sup>4</sup> Rajalakshmi S

## Recognition of Energy Harvesting Techniques for Enhanced Operation in WSN Using IoT with Deep Learning



**Abstract:** - The recognition of energy harvesting techniques for enhanced operation in Wireless Sensor Networks (WSN) using IoT and deep learning entails a novel approach to improving the energy efficiency and operational durability of sensor nodes deployed in various environments. Energy harvesting refers to the process of collecting energy from diverse sources such as solar power, thermal energy, wind energy, and mechanical vibrations, and converting it into electrical energy to power electronic devices, including sensor nodes in a WSN. The integration of the Internet of Things with WSNs allows for interconnectivity, enabling enhanced communication, data exchange, and remote management capabilities. This integration facilitates the deployment of more intelligent and adaptive sensor networks, capable of making decisions based on collected information. Deep learning, a subset of machine learning, plays a vital role in enhancing the operation of WSNs by providing advanced data analysis and predictive modeling capabilities. Through the utilization of deep learning algorithms, the proposed system can forecast energy consumption patterns, identify optimal periods for energy harvesting, and optimize the energy efficiency of sensor nodes. This includes adjusting operational parameters such as data communication rates or sleep cycles based on the predicted availability of harvested energy. Deep learning also aids in identifying and prioritizing the most viable energy sources in the deployment environment of the WSN. By employing appropriate energy harvesting techniques based on environmental conditions, such as solar energy harvesting in summer or mechanical vibration harvesting in industrial settings, the proposed method ensures more efficient operation and sustainability of sensor networks across various applications.

**Keywords:** Energy Harvesting Techniques, Wireless Sensor Networks, Internet of Things, deep learning, sustainability.

### I. INTRODUCTION

Wireless Sensor Networks (WSN) have emerged as a transformative innovation in wireless communication and networking, facilitating the deployment of numerous sensor nodes for the purpose of monitoring and gathering data from the surrounding environment [1]–[3]. These sensor nodes are equipped with an array of sensors, processing units, and wireless communication capabilities, working collaboratively to capture, process, and transmit data to a centralized location for analysis and application across various domains. The versatility of WSNs has led to their widespread adoption in diverse fields such as environmental monitoring, healthcare, industrial automation, military surveillance, and the development of smart cities [4]–[6].

However, the design and implementation of WSNs come with inherent challenges that need to be addressed. These challenges include but are not limited to, the constraints of limited energy resources, scalability issues, the aggregation of data from multiple nodes, and concerns regarding the security of transmitted data. Despite these challenges, ongoing advancements in microelectronics, wireless communication technologies, and energy harvesting techniques have continuously expanded the capabilities and potential applications of WSNs. These advancements have enabled WSNs to facilitate real-time monitoring and decision-making processes based on the collection of accurate and reliable environmental data [7]–[9].

<sup>1</sup> \*Corresponding Author: Associate Professor, Department of CSE, GITAM School of Technology, GITAM (Deemed to be) University, Bengaluru Campus. Email: deancseit@gmail.com, ORCID: 0000-0002-4105-2793

<sup>2</sup> Professor, Department of Computer Science and Engineering, S.A. Engineering College (Autonomous), Poonamallee-Avadi Road, Thiruverkadu, Chennai-600077, Tamil Nadu, India. Email: hemanand1982@gmail.com, ORCID: 0000-0002-3693-3350

<sup>3</sup> Professor, Department of Computer Science & Engineering, R.M.D Engineering College, Kavaraipettai 601206.  
Email: psr.cse@rmd.ac.in, ORCID: 0000-0002-5465-8444

<sup>4</sup> Assistant Professor, Department of CSE, Velammal Engineering College, Chennai. Email: rajalakshmis@velammal.edu.in,  
ORCID: 0000-0002-2963-9057

Artificial Intelligence (AI) plays a pivotal role in augmenting the efficiency, reliability, and functionality of Wireless Sensor Networks (WSNs). Characterized by spatially distributed autonomous sensors, WSNs are tasked with monitoring physical or environmental conditions and transmitting the gathered data to a central processing unit for further analysis. The integration of AI into WSNs introduces intelligent algorithms and data analytics capabilities, thereby enabling the network to perform complex tasks such as data filtering, anomaly detection, and predictive maintenance [10]–[12].

WSNs can use AI technologies to filter irrelevant data, detect unusual patterns or anomalies in data, and predict potential system failures or maintenance needs. With the ability to undertake these functions and the features of AI tools, WSNs can greatly extend their utility for industries [13]–[15]. These functions are especially useful in settings where timely and accurate data analysis is vital to the decision-making process. Moreover, WSNs that incorporate AI-based technologies make use of these capabilities. They adjust their behavior in response to environmental change or changing system needs, saving power and extending sensor node life [16]–[18].

Moreover, with the integration of AI in WSNs a new class of data analytics techniques that can be called "sophisticated" are available. They are able to extract valuable insights from the data by analyzing and correlating multidimensional data. Independent analysts believe that these insights can help decision makers in making policies for environmental monitoring, natural resource management, and healthcare diagnostics as well as industrial process optimization. From the perspective of Wireless Sensor Networks (WSN), which have been so inherently dependent on limited energy resources; the most important issues are energy efficiency and environmental protection. As such, the development and implementation of energy harvesting techniques have garnered significant attention in recent years. These devices, invented to extract ambient energy sources from the environment--solar radiation, heat or mechanical movement--enable sensor nodes to operate without batteries. Energy cannot be generated, but only exchanged: these non-traditional sources (ambient) must also be employed! The integration of energy harvesting techniques into sensor networks could greatly extend their operational life spans and provide autonomy for various applications [19]-[21].

Many studies have recently been done in a variety of areas on WSNs. These have looked into the economic viability and societal acceptance of energy harvesting. For example, some research is on the design and optimization for energy harvesting systems which aims to optimize energy conversion efficiency as well as secure energy supply to nodes. Techniques such as maximum power point tracking (MPPT) algorithms or adaptive energy management strategies were also examined systematically to improve the performance of energy harvesting systems and make the energy use efficient [22]–[24].

In addition, combining WSN with IoT technologies can bring new functions and applications into energy collection's methods. Energy harvesting systems exchange real-time data and make determinations of their own based upon intelligence. Such systems can take advantage of the link between sensor nodes and IoT platforms, so that they allow smooth connection and communication. IoT energy harvesting systems enable remote control, monitoring and optimization of energy harvesting processes for higher efficiency and reliability [25]–[27].

Another good way to optimize energy harvesting systems in WSNs is by using deep learning algorithms. These programs can process the large packets of data streaming from sensor nodes and IoT devices, identify patterns and trends, and tell you accurately how much power is available with the consumption patterns going on. With deep learning techniques, the mode of operation for energy harvesting systems will dynamically alter in response to changes in the surroundings or requirements of power. This way, networks of sensors can make the best use of energy and extend their lives [22], [28]-[30].

Energy harvesting systems for WSNs have wasted a lot of time on deep learning algorithms, with many research efforts. Studies have already shown that deep learning makes better use of battery power, optimizes the energy harvesting process, and improves network performance and resource utilization greatly. In energy harvesting systems that take full advantage of deep learning methods, they are really able to. This is precisely that has allowed the deployment of WSNs in a variety of difficult environments and conditions [31]-[33].

On the whole, when combined with IoT technologies and deep learning algorithms, tie-ups between WSNs and techniques for collecting energy also show great promise in transforming the wireless sensor network domain. Energy harvesting systems can make WSNs self-sustainable and free from the constraints imposed by the commonly-used battery power supplies. This means that wireless sensor networks can be used in a wide range of

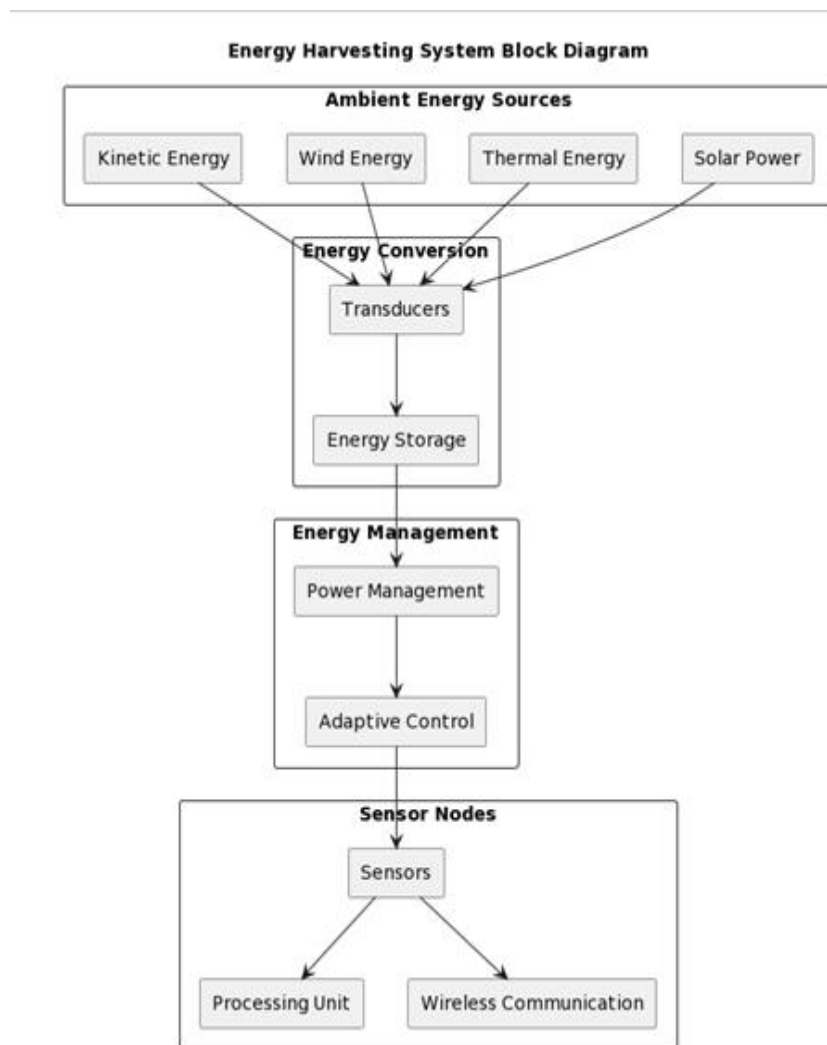
applications such as monitoring the environment, supporting health care, controlling industry or building smart cities. If research in this area continues to develop, there will be much potential for innovation and impact in energy harvesting systems for WSNs.

## II. METHODOLOGY

### 1.1. Energy Source Identification and Harvesting

Figure 1 shows, wireless sensor networks (WSNs), capturing and deploying various environmental energy sources for energy harvesting is vital for reducing reliance on traditional battery power and extending the life span of the sensor node. This involves recognizing (and making use of) the various ambient energy sources to be had in the deployment environment. These range from solar power, thermal energy, wind energy--in disciplines that use wheels--to kinetic energy waiting for your grab. Through the use of advanced methods and algorithms, it is possible to evaluate the availability, intensity and reliability of the carriers so that they never stop delivering electricity supplies to sensor nodes. With these energy sources harnessed, WSNs are ensured greater sustainability as well as autonomy - operating for extended time periods in a wide variety of environmental conditions.

### 1.2. Energy Conversion and Storage



**Figure 1. Proposed Approach**

The goal of energy harvesting in WSNs is to convert and store ambient energy into electricity in order to power sensor nodes. Transducers like photovoltaic cells, thermoelectric generators, piezoelectric elements, RF harvesters are used to convert environmental energy into electricity. Batteries or supercapacitor devices are particularly important as an efficient means of storing energy, ensuring continuous and reliable operation of sensors even with variable or intermittent ambient energy sources. WSNs, through improving energy conversion and storage

processes, can improve the efficiency with which they use their energy sources, and in turn, can significantly enhance notebook's overall network performance and reliability.

### ***1.3. Data Collection and Pre-processing***

The data must first be collected from sensor networks and preprocessed to be used for predictive modeling and analysis. In the course of this operation, raw sensor data is cleaned, normalized, and feature-extracted to present all of their pertinent features concerning energy harvesting and consumption patterns. Temporal features are crucial for deriving time series estimates in energy harvesting that take into account any variation of energy availability or sensor network conditions. WSNs may improve the accuracy and reliability of forecasting models by performing more effective pre-processing on data. This will enable improved decision making and also pave the way for energy management strategies to be optimized.

### ***1.4. Feature Extraction using CNN***

Computer networks have been very concerned about the new energy harvesting technology. When CNNs perform feature extraction, very little energy is consumed. Such processing of data collected by spatial sensor networks could help detect any patterns in them, while at the same time picking out anomalies or significant events. Data collected by temperature, humidity, and vibration sensors is also processed by CNNs to reduce energy consumption in network operations for longer. Systems of energy harvesting are being used to make WSN more reliable and efficient. This will permit them to adjust better to changes in nature and be more sustainable.

### ***1.5. Sequence Data Handling with RNN***

WSNs for predicting future energy availability and consumption patterns have a recurrent neural network (RNN) to handle sequence data. The forecast comes from learning of past trends in RNNs on energy of environmental origins as well to balance power consumption in the network, making it stable even under environmental changes. RNNs in WSNs with their advantages allow for increased efficiency and self-sufficiency; that in turn makes adaptive energy management algorithms possible, and it can also keep the network going for longer periods of time without assistance.

### ***1.6. Energy Usage Optimization***

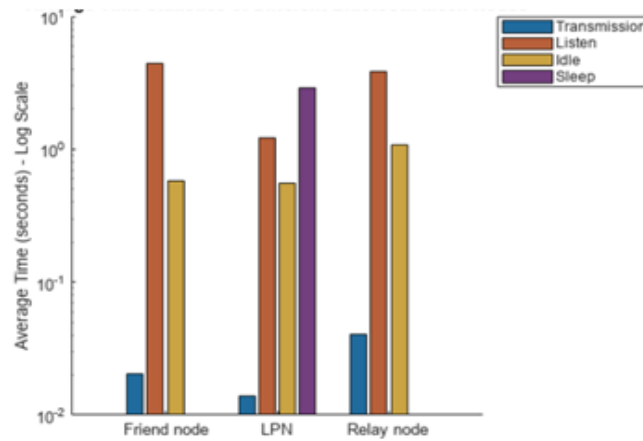
RNN and LSTM networks can be used for energy management to better use the WSNs that rely on energy-harvesting technology. LSTM and RNN technologies involve predicting future energy availability and consumption patterns, and by doing so adjusting sensor activities and communications protocols. Energy usage is maximized while the network's operational lifespan is extended. As a result of energy optimization, WSNs can be sustainable and reliable no matter about the circumstances they are in, and can thus operate independently in different environmental conditions.

### ***1.7. Data Transmission and Predictive Analysis using Deep Learning***

With deep-learning technology such as CNNs, RNNs, and LSTMs, data transmitted over WSNs is used for predictive analytics that optimize energy usage based on predicted conditions. Anticipatory models predict how much energy can be expected, and how much will be consumed. As a result, models which track the patterns and energy availability and usage in future forecasts have made it possible for us to adapt in a timely manner to new environmental conditions, and efficiently utilize renewable energy sources. With the capabilities of deep learning, WSNs can obtain greater efficiency and reliability, thereby prolonging performance across a wide spectrum of applications.

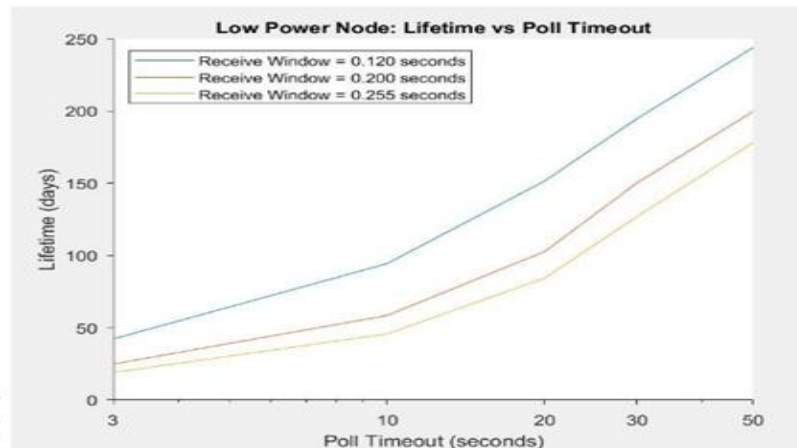
## **III. RESULT AND DISCUSSION**

The proposed system is implemented in Matlab Simulink to evaluate the performance of the proposed system. Figure 2 shows the traffic calculation between mesh nodes. Traffic calculation in mesh nodes is essential for optimizing network performance and reliability in mesh networks. Mesh networks, characterized by multiple nodes that directly communicate with each other which are dependent on efficient traffic distribution to confirm smooth data transmission across the network.



**Figure 2. Traffic Calculation Between Mesh Nodes**

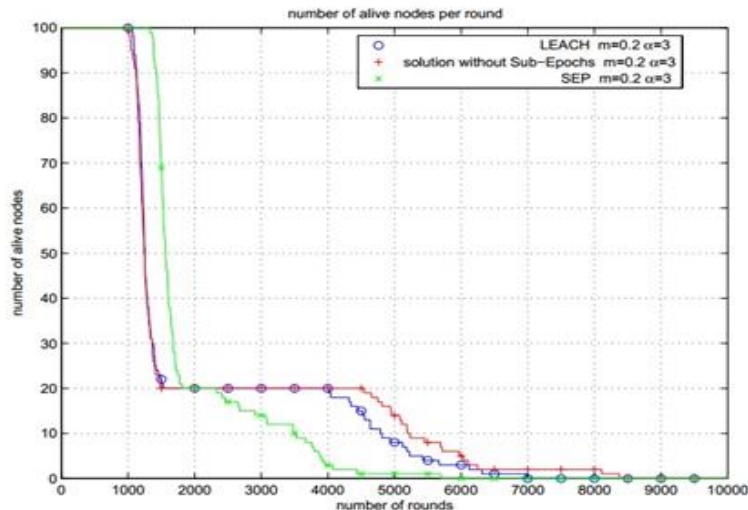
Figuring out traffic in mesh mode makes it possible for networks to identify congestion, prioritize data packets, and route traffic away from overload points so important when your network is busy or its configuration changes. This process is important if you want to deliver quality service when network demand is high or the topology is a dynamic one. Traffic calculations also help with network planning and expansion, as they provide clues about how the system is presently used and how it might be used. This helps the decision-making process when deciding on infrastructure improvements, as well.



**Figure 3. Node Analysis**

Figure 3 represents the node analysis. The preceding plot accomplishes that the lifetime of LPN is directly proportional to the poll timeout. Figure 4 represents the active node analysis. The graph is evaluated using a feedback loop. The feedback loop involves the uninterrupted monitoring of the network's energy status and environmental conditions. The analysis and forecast of energy patterns using CNNs, RNNs, and LSTM and the successive variation of energy harvesting and consumption policies.

The loop ensures that the making decisions process incorporates data and flexibility, so it can quickly change in response to energy or network demand changes. With the aid of CNNs, RNNs and LSTMs, techniques for harvesting energy in WSGs can significantly enhance the efficiency and sustainability of this network, thereby prolonging the life of its members and civilizing their behavior.



**Figure 4. Energy Harvesting Analysis**

Integrating RNN and LSTM models into energy-harvesting WSN management represents an active and intelligent approach to energy optimization. It does not simply lengthen the network's service life, but also by making sensor nodes active and responsive over fluctuating environmental energy sources reliably, maintains their performance. Such an approach shows the power of machine learning in making wireless sensor networks more self-directed, cost-effective, and sustainable from an energy and environmental perspective.

#### IV. CONCLUSION

Embedded systems have achieved significant progress in the integration of energy harvesting technologies with IoT platforms and deep learning algorithms. This shows that wireless sensor networks (WSNs) are moving towards the important objective of improved effectiveness and sustainability. By harnessing waste energy and smart data analysis to predict better future trends, WSNs can operate forever long periods without any need for frequent maintenance; this reduces costs and improves reliability not only in a few particular applications, but also across a broad arc of new kinds of situations. This integration not only meets the challenges posed by finite energy resources, it also offers opportunities to develop more resilient and "recovery-able" sensor networks that are efficient and self-sustaining. WSNs can carry out their monitoring and communication tasks effectively by enabling continuous operation and adaptive energy management, which is also helping to advance environmental monitoring, healthcare, industrial automation, and smart city initiatives. As a result, the combination of energy harvesting techniques with IoT platforms and deep learning algorithms is an entirely new way to improve the performance and sustainability of WSNs--all alongside opening up new possibilities for innovation and impact in the realm of wireless sensing and communication.

#### REFERENCES

- [1] P. Álvarez, F. J. Zarazaga-Soria, and S. Baldassarri, "Mobile music recommendations for runners based on location and emotions: The DJ-Running system," *Pervasive Mob. Comput.*, vol. 67, p. 101242, 2020, doi: 10.1016/j.pmcj.2020.101242.
- [2] Q. Chen, "Music Teaching Software Development Based on Neural Network Algorithm and User Analysis," *Entertain. Comput.*, vol. 49, no. December 2023, p. 100631, 2023, doi: 10.1016/j.entcom.2023.100631.
- [3] H. Gao and F. Li, "The application of virtual reality technology in the teaching of clarinet music art under the mobile wireless network learning environment," *Entertain. Comput.*, vol. 49, no. October 2023, p. 100619, 2024, doi: 10.1016/j.entcom.2023.100619.
- [4] A. Asha, R. Arunachalam, I. Poonguzhali, S. Urooj, and S. Alelyani, "Optimized RNN-based performance prediction of IoT and WSN-oriented smart city application using improved honey badger algorithm," *Measurement*, vol. 210, no. July 2022, p. 112505, 2023, doi: 10.1016/j.measurement.2023.112505.

- [5] W. Li and S. Kara, "Methodology for Monitoring Manufacturing Environment by Using Wireless Sensor Networks (WSN) and the Internet of Things (IoT)," *Procedia CIRP*, vol. 61, pp. 323–328, 2017, doi: 10.1016/j.procir.2016.11.182.
- [6] M. Singh and P. M. Khilar, "A Range Free Geometric Technique for Localization of Wireless Sensor Network (WSN) Based on Controlled Communication Range," *Wirel. Pers. Commun.*, vol. 94, no. 3, pp. 1359–1385, 2017, doi: 10.1007/s11277-016-3686-x.
- [7] R. Karthikeyan, K. Sakthisudhan, G. Sreena, C. Veevasvan, and S. Yuvasri, "Industry safety measurement using multi-sensing robot with IIoT," *Mater. Today Proc.*, vol. 45, pp. 8125–8129, 2021, doi: 10.1016/j.matpr.2021.01.919.
- [8] V. S. Badiger and T. S. Ganashree, "Data aggregation scheme for IOT based wireless sensor network through optimal clustering method," *Meas. Sensors*, vol. 24, no. August, p. 100538, 2022, doi: 10.1016/j.measen.2022.100538.
- [9] S. Basagni, A. Carosi, E. Melachrinoudis, C. Petrioli, and Z. M. Wang, "Controlled sink mobility for prolonging wireless sensor networks lifetime," *Wirel. Networks*, vol. 14, no. 6, pp. 831–858, 2008, doi: 10.1007/s11276-007-0017-x.
- [10] A. Kishore Kumar, M. Aeri, A. Grover, J. Agarwal, P. Kumar, and T. Raghu, "Secured supply chain management system for fisheries through IoT," *Meas. Sensors*, vol. 25, no. August 2022, p. 100632, 2023, doi: 10.1016/j.measen.2022.100632.
- [11] R. R. Swain and P. M. Khilar, "Composite Fault Diagnosis in Wireless Sensor Networks Using Neural Networks," *Wirel. Pers. Commun.*, vol. 95, no. 3, pp. 2507–2548, 2017, doi: 10.1007/s11277-016-3931-3.
- [12] Q. Zhang and K. Zhang, "Protecting Location Privacy in IoT Wireless Sensor Networks through Addresses Anonymity," *Secur. Commun. Networks*, vol. 2022, 2022, doi: 10.1155/2022/2440313.
- [13] P. Aeruginosa, "Adaptation of Hand Exoskeletons for Occupational Augmentation: A Literature Review," *Rob. Auton. Syst.*, vol. 174, no. July 2023, p. 104618, 2023, doi: 10.1016/j.robot.2024.104618.
- [14] A. Battezzato, "Kinetostatic analysis and design optimization of an n-finger underactuated hand exoskeleton," *Mech. Mach. Theory*, vol. 88, pp. 86–104, 2015, doi: 10.1016/j.mechmachtheory.2014.12.007.
- [15] S. Kim, J. Lee, and J. Bae, "Analysis of Finger Muscular Forces using a Wearable Hand Exoskeleton System," *J. Bionic Eng.*, vol. 14, no. 4, pp. 680–691, 2017, doi: 10.1016/S1672-6529(16)60434-1.
- [16] N. Ferehan, A. Haqiq, and M. W. Ahmad, "Smart Farming System Based on Intelligent Internet of Things and Predictive Analytics," *J. Food Qual.*, vol. 2022, 2022, doi: 10.1155/2022/7484088.
- [17] S. R. Vijayalakshmi and S. Muruganand, "A survey of Internet of Things in fire detection and fire industries," *Proc. Int. Conf. IoT Soc. Mobile, Anal. Cloud, I-SMAC 2017*, pp. 703–707, 2017, doi: 10.1109/I-SMAC.2017.8058270.
- [18] P. I. Priya, S. Muthurajkumar, and S. S. Daisy, "Data Fault Detection in Wireless Sensor Networks Using Machine Learning Techniques," *Wirel. Pers. Commun.*, vol. 122, no. 3, pp. 2441–2462, 2022, doi: 10.1007/s11277-021-09001-1.
- [19] M. Preetha, Archana A B, K. Ragavan, T. Kalaihelvi, M. Venkatesan "A Preliminary Analysis by using FCGA for Developing Low Power Neural Network Controller Autonomous Mobile Robot Navigation", *International Journal of Intelligent Systems and Applications in Engineering (IJISAE)*, ISSN:2147-6799. Vol:12, issue 9s, Page No:39-42, 2024
- [20] Maheswaran K, Aloysius A, "An Interface based Cognitive Weighted Class Complexity Measure for Object Oriented Design", *International Journal of Pure and Applied Mathematics*, Vol. 118, No. 18, pp. 2771-2778, 2018
- [21] A. Sharma, P. K. Singh, and Y. Kumar, "An integrated fire detection system using IoT and image processing technique for smart cities," *Sustain. Cities Soc.*, vol. 61, no. December 2019, p. 102332, 2020, doi: 10.1016/j.scs.2020.102332
- [22] M. Preetha, Raja Rao Budaraju, Jackulin. C, P. S. G. Aruna Sri, T. Padmapriya "Deep Learning-Driven Real-Time Multimodal Healthcare Data Synthesis", *International Journal of Intelligent Systems and Applications in Engineering (IJISAE)*, ISSN:2147-6799, Vol.12, Issue 5, page No:360-369, 2024.
- [23] N. EA, D. Tamilarasi, S. Sasikala, R. R. Nair, and K. . Uma, "An Efficient Food Quality Analysis Model (EFQAM) using the Internet of Things (IoT) Technologies," *Microprocess. Microsyst.*, p. 103972, 2021, doi: 10.1016/j.micpro.2021.103972.

- [24] Syed Tanzeel Rabani, Maheswaran K, "Software Cognitive Complexity Metrics for OO Design: A Survey", *International Journal of Scientific Research in Science, Engineering and Technology*, Vol. 3 , No. 3, pp. 691-698, June 2017.
- [25] S. H. Park, D. H. Kim, and S. C. Kim, "Recognition of IoT-based fire-detection system fire-signal patterns applying fuzzy logic," *Heliyon*, vol. 9, no. 2, p. e12964, 2023, doi: 10.1016/j.heliyon.2023.e12964.
- [26] Srinivasan, S, Hema, D. D, Singaram, B, Praveena, D, Mohan, K. B. K, & Preetha, M. (2024), "Decision Support System based on Industry 5.0 in Artificial Intelligence", *International Journal of Intelligent Systems and Applications in Engineering (IJISAE)*, ISSN:2147-6799, Vol.12, Issue 15, page No-172-178.
- [27] V. Lakshmikantha, A. Hiriyannagowda, A. Manjunath, A. Patted, J. Basavaiah, and A. A. Anthony, "IoT based smart water quality monitoring system," *Glob. Transitions Proc.*, vol. 2, no. 2, pp. 181–186, 2021, doi: 10.1016/j.gltp.2021.08.062.
- [28] S. Ding, A. Tukker, and H. Ward, "Opportunities and risks of internet of things (IoT) technologies for circular business models: A literature review," *J. Environ. Manage.*, vol. 336, no. March, p. 117662, 2023, [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0301479723004504>
- [29] Z. Chen, X. Feng, and S. Zhang, "Emotion detection and face recognition of drivers in autonomous vehicles in IoT platform," *Image Vis. Comput.*, vol. 128, p. 104569, 2022, doi: 10.1016/j.imavis.2022.104569.
- [30] R. Guo and Z. Zhong, "Advanced Engineering Informatics A customer-centric IoT-based novel closed-loop supply chain model for WEEE management," *Adv. Eng. Informatics*, vol. 55, no. July 2022, p. 101899, 2023, doi: 10.1016/j.aei.2023.101899.
- [31] T. Kozłowski and O. Noran, "ScienceDirect ScienceDirect Designing Designing an an Evaluation Evaluation Framework Framework for for IoT IoT Environmental Environmental Monitoring Systems Systems Monitoring," *Procedia Comput. Sci.*, vol. 219, pp. 220–227, 2023, doi: 10.1016/j.procs.2023.01.284.
- [32] R. M. Bhavadharini, S. Karthik, N. Karthikeyan, and A. Paul, "Wireless Networking Performance in IoT Using Adaptive Contention Window," *Wirel. Commun. Mob. Comput.*, vol. 2018, 2018, doi: 10.1155/2018/7248040.
- [33] J. Xu, B. Gu, and G. Tian, "Review of agricultural IoT technology," *Artif. Intell. Agric.*, vol. 6, pp. 10–22, 2022, doi: 10.1016/j.iiia.2022.01.001.