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Integrated Heat Recovery Cooling Mechanism for HEVs

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Abstract: Hybrid Electric Vehicles (HEVs) are rapidly gaining traction as a sustainable alternative to conventional vehicles, thanks to their ability to reduce fuel consumption and lower emissions. However, HEVs generate a significant amount of heat during operation, particularly in the powertrain and battery systems, which can reduce efficiency and lead to component degradation. This paper proposes an Integrated Heat Recovery Cooling Mechanism (IHR-CM) for HEVs that combines conventional cooling systems with advanced heat recovery techniques. The mechanism uses thermoelectric generators (TEGs) to capture waste heat from the engine, battery, and power electronics, converting it into usable energy for the vehicle's auxiliary systems or battery recharging. Additionally, an AI-driven thermal management system is integrated into the IHR-CM to optimize cooling processes based on real-time driving conditions. This proactive cooling management reduces energy consumption and improves the overall thermal efficiency of HEVs. The proposed system is designed to extend the lifespan of critical components, improve vehicle efficiency, and reduce the overall energy demand on the battery. Through a comprehensive analysis of existing cooling systems and heat recovery technologies, this paper outlines how the IHR-CM can address the challenges associated with thermal management in HEVs, leading to enhanced performance and sustainability.

Keywords: Hybrid Electric Vehicle (HEV), Heat Recovery, Cooling System, Thermoelectric Generator (TEG), Waste Heat, Energy Efficiency, AI-Based Thermal Management, Battery Cooling, Powertrain Thermal Regulation, Smart Cooling Systems.

1. INTRODUCTION

As the global demand for environmentally friendly vehicles increases, Hybrid Electric Vehicles (HEVs) have emerged as a practical solution to reduce greenhouse gas emissions and improve fuel efficiency. These vehicles integrate both internal combustion engines (ICEs) and electric propulsion systems, offering the benefits of both while minimizing the environmental impact. However, with this integration comes the challenge of managing significant amounts of heat generated by key components, such as the powertrain, battery systems, and power electronics.

Effective thermal management is essential to ensure the longevity, safety, and performance of HEVs. Overheating in critical components can lead to efficiency losses, accelerated wear and tear, and even system failures. Traditional cooling systems used in HEVs, such as air cooling and liquid cooling, are designed to dissipate excess heat, but they do not capture and reuse the waste heat effectively. This results in lost energy and reduced overall vehicle efficiency.

To address this issue, the concept of heat recovery has been introduced, wherein waste heat generated by the vehicle's components is captured and repurposed to reduce energy losses. Heat recovery systems can convert waste heat into usable energy, which can be redirected to power the vehicle's auxiliary systems or recharge the battery. By combining heat recovery with an advanced cooling system, it is possible to not only manage the thermal load more efficiently but also enhance the overall energy efficiency of the HEV.

This paper introduces the Integrated Heat Recovery Cooling Mechanism (IHR-CM), a system designed to capture and reuse waste heat in HEVs. The IHR-CM integrates thermoelectric generators (TEGs) to convert heat into electrical energy and employs AI-based thermal management to dynamically adjust cooling efforts based on real-time driving conditions. This approach aims to improve the cooling efficiency, reduce the energy demand on the battery, and extend the lifespan of HEV components. Through a review of existing cooling technologies and an exploration of innovative heat recovery methods, this paper presents the IHR-CM as a cutting-edge solution to the thermal management challenges in HEVs.

2. LITERATURE SURVEY

Thermal management in HEVs is a critical area of research, as effective cooling is essential for maintaining the performance and reliability of the vehicle's components. Traditional cooling systems, such as liquid cooling and air cooling, have been widely implemented in HEVs to dissipate heat generated by the internal combustion engine (ICE), electric motors, and power electronics. However, these systems are often limited by their inability to capture and reuse waste heat, which leads to energy losses and reduced efficiency.

Li et al. (2017) conducted a study on the application of thermoelectric generators (TEGs) in HEVs, demonstrating that TEGs can effectively capture waste heat from the exhaust system and convert it into electrical energy. This energy can be used to power auxiliary systems or recharge the vehicle's battery. While the study highlighted the potential of TEGs to improve energy efficiency, it also noted the challenges of integrating TEGs into the existing thermal management systems of HEVs.

Zhang et al. (2019) explored the use of heat exchangers to manage the heat generated by power electronics and battery systems in HEVs. Their research demonstrated that advanced heat exchangers could improve heat dissipation while minimizing energy consumption. However, the study pointed out that conventional heat exchangers are often not adaptable to changing driving conditions, leading to inefficiencies in heat management.

Recent advancements in artificial intelligence (AI) have paved the way for more intelligent and adaptive cooling systems in HEVs. Wang et al. (2021) introduced an AI-based thermal management system that uses machine learning algorithms to predict thermal loads and optimize cooling efforts based on real-time data. Their study demonstrated that AI can significantly improve cooling efficiency by dynamically adjusting cooling efforts to match the vehicle's operating conditions. However, the study did not explore the integration of heat recovery technologies into the AI-driven cooling system.

Despite these advancements, there is a lack of research on systems that integrate heat recovery with AI-based thermal management in HEVs. Most existing systems focus on either cooling or heat recovery, but not both. This paper builds on previous research by proposing an Integrated Heat Recovery Cooling Mechanism (IHR-CM) that combines TEGs, heat exchangers, and AI-driven thermal management to optimize the cooling and energy efficiency of HEVs.

3. PROPOSED SYSTEM

The Integrated Heat Recovery Cooling Mechanism (IHR-CM) is designed to capture and reuse waste heat generated by HEV components, while also optimizing the cooling process using AI-driven thermal management. The system is composed of three main components: thermoelectric generators (TEGs), advanced heat exchangers, and an AI-based thermal management system.

3.1 Thermoelectric Generators (TEGs)

TEGs are used to capture waste heat from the exhaust system, engine, power electronics, and battery pack. The TEGs convert this waste heat into usable electrical energy, which can be redirected to power auxiliary systems such as air conditioning, or to recharge the vehicle's battery. The TEGs are strategically placed around the hottest components of the HEV to maximize heat capture and conversion efficiency.

3.2 Advanced Heat Exchangers

The IHR-CM incorporates multi-phase heat exchangers that are designed to manage the heat dissipation needs of the battery pack, electric motor, and power electronics. These heat exchangers use phase-change materials (PCMs) to absorb excess heat during high-load conditions and release stored heat during low-load conditions. This approach ensures efficient cooling across a wide range of operating conditions.

3.3 AI-Based Thermal Management

The AI-based thermal management system continuously monitors the temperature of critical components in real-time, using data collected from temperature sensors embedded in the vehicle. The AI system employs machine learning algorithms to predict future thermal loads and dynamically adjust the cooling system to prevent overheating or energy waste. The AI-driven system ensures that cooling efforts are optimized based on current driving conditions, reducing energy consumption and improving the overall thermal efficiency of the vehicle.

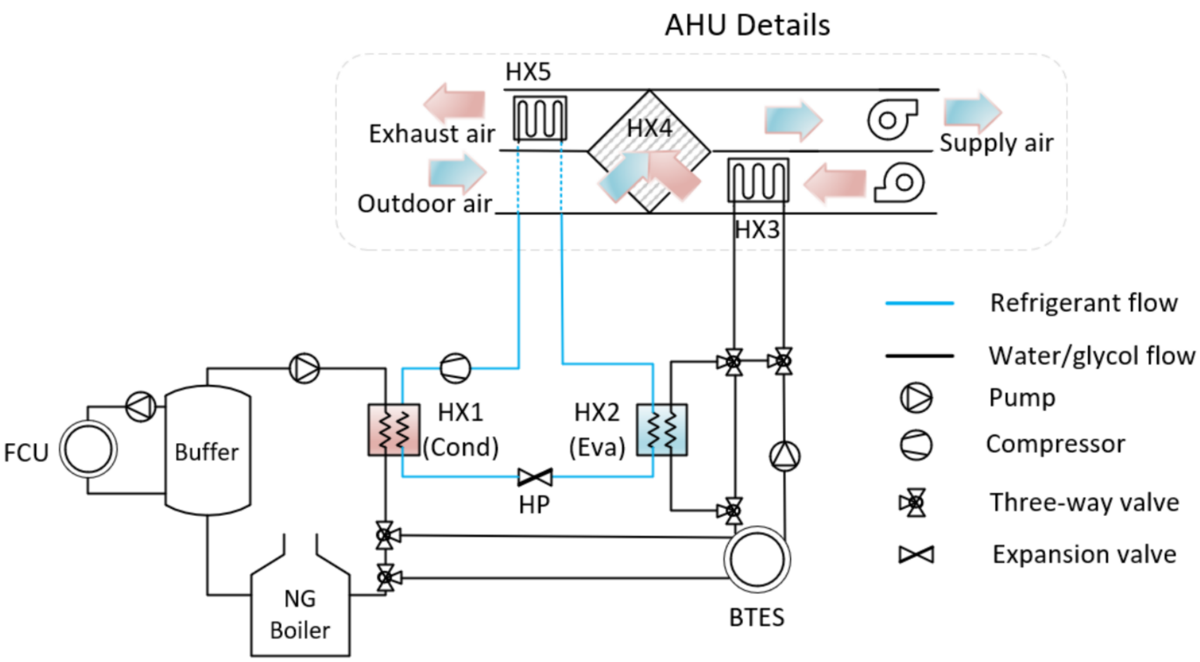

FIGURE 1: A Systematic Heat Recovery Approach for Designing Integrated Heating, Cooling, and Ventilation Systems

4. CONCLUSION

The Integrated Heat Recovery Cooling Mechanism (IHR-CM) offers a novel approach to addressing the thermal management challenges in Hybrid Electric Vehicles (HEVs). By combining traditional cooling methods with heat recovery technologies, such as thermoelectric generators (TEGs) and advanced heat exchangers, the system captures waste heat and repurposes it for auxiliary power or battery recharging. The integration of AI-based thermal management further enhances the system's efficiency by dynamically adjusting cooling efforts based on real-time driving conditions. This approach not only reduces energy consumption but also improves the overall performance and lifespan of HEV components. As HEVs continue to evolve, the IHR-CM represents a promising solution for optimizing thermal management and energy efficiency in future hybrid vehicle designs.

REFERENCES

1. Lopez, S., Sarada, V., Praveen, R. V. S., Pandey, A., Khuntia, M., & Haralayya, D. B. (2024). Artificial intelligence challenges and role for sustainable education in india: Problems and prospects. *Sandeep*

Lopez, Vani Sarada, RVS Praveen, Anita Pandey, Monalisa Khuntia, Bhadrappa Haralayya (2024) Artificial Intelligence Challenges and Role for Sustainable Education in India: Problems and Prospects. Library Progress International, *44*(3), 18261-18271.

2. Kumar, N., Kurkute, S. L., Kalpana, V., Karuppannan, A., Praveen, R. V. S., & Mishra, S. (2024, August). Modelling and Evaluation of Li-ion Battery Performance Based on the Electric Vehicle Tiled Tests using Kalman Filter-GBDT Approach. In *2024 International Conference on Intelligent Algorithms for Computational Intelligence Systems (IACIS)* (pp. 1-6). IEEE.
3. Sharma, S., Vij, S., Praveen, R. V. S., Srinivasan, S., Yadav, D. K., & VS, R. K. (2024, October). Stress Prediction in Higher Education Students Using Psychometric Assessments and AOA-CNN-XGBoost Models. In *2024 4th International Conference on Sustainable Expert Systems (ICSES)* (pp. 1631-1636). IEEE.
4. Yamuna, V., Praveen, R. V. S., Sathya, R., Dhivva, M., Lidiya, R., & Sowmiya, P. (2024, October). Integrating AI for Improved Brain Tumor Detection and Classification. In *2024 4th International Conference on Sustainable Expert Systems (ICSES)* (pp. 1603-1609). IEEE.
5. Anuprathibha, T., Praveen, R. V. S., Jayanth, H., Sukumar, P., Suganthi, G., & Ravichandran, T. (2024, October). Enhancing Fake Review Detection: A Hierarchical Graph Attention Network Approach Using Text and Ratings. In *2024 Global Conference on Communications and Information Technologies (GCCIT)* (pp. 1-5). IEEE.
6. Praveen, R. V. S. (2024). *Data Engineering for Modern Applications*. Addition Publishing House.
7. Dhivya, R., Sagili, S. R., Praveen, R. V. S., VamsiLala, P. N. V., Sangeetha, A., & Suchithra, B. (2024, December). Predictive Modelling of Osteoporosis using Machine Learning Algorithms. In *2024 4th International Conference on Ubiquitous Computing and Intelligent Information Systems (ICUIS)* (pp. 997-1002). IEEE.
8. Kemmannu, P. K., Praveen, R. V. S., Saravanan, B., Amshavalli, M., & Banupriya, V. (2024, December). Enhancing Sustainable Agriculture Through Smart Architecture: An Adaptive Neuro-Fuzzy Inference System with XGBoost Model. In *2024 International Conference on Sustainable Communication Networks and Application (ICSCNA)* (pp. 724-730). IEEE.
9. Praveen, R. V. S., Raju, A., Anjana, P., & Shibi, B. (2024, October). IoT and ML for Real-Time Vehicle Accident Detection Using Adaptive Random Forest. In *2024 Global Conference on Communications and Information Technologies (GCCIT)* (pp. 1-5). IEEE.
10. Praveen, R. V. S., Hemavathi, U., Sathya, R., Siddiq, A. A., Sanjay, M. G., & Gowdish, S. (2024, October). AI Powered Plant Identification and Plant Disease Classification System. In *2024 4th International Conference on Sustainable Expert Systems (ICSES)* (pp. 1610-1616). IEEE.
11. Thamilarasi, V., & Roselin, R. (2021, February). Automatic classification and accuracy by deep learning using cnn methods in lung chest X-ray images. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1055, No. 1, p. 012099). IOP Publishing.
12. Thamilarasi, V., & Roselin, R. (2019). Lung segmentation in chest X-ray images using Canny with morphology and thresholding techniques. *Int. j. adv. innov. res*, *6*(1), 1-7.
13. Thamilarasi, V., & Roselin, R. (2019). Automatic thresholding for segmentation in chest X-ray images based on green channel using mean and standard deviation. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, *8*(8), 695-699.
14. Thamilarasi, V., & Roselin, R. (2021). U-NET: convolution neural network for lung image segmentation and classification in chest X-ray images. *INFOCOMP: Journal of Computer Science*, *20*(1), 101-108.
15. Asaithambi, A., & Thamilarasi, V. (2023, March). Classification of Lung Chest X-Ray Images Using Deep Learning with Efficient Optimizers. In *2023 IEEE 13th Annual Computing and Communication Workshop and Conference (CCWC)* (pp. 0465-0469). IEEE.
16. Jadhav, S., Machale, A., Mharnur, P., Munot, P., & Math, S. (2019, September). Text based stress detection techniques analysis using social media. In *2019 5th International Conference On Computing, Communication, Control And Automation (ICCUBEA)* (pp. 1-5). IEEE.
17. Anitha, C., Tellur, A., Rao, K. B., Kumbhar, V., Gopi, T., Jadhav, S., & Vidhya, R. G. (2024). Enhancing Cyber-Physical Systems Dependability through Integrated CPS-IoT Monitoring. *International Research Journal of Multidisciplinary Scope*, *5*(2), 706-713.
18. Kiran, A., Sonker, A., Jadhav, S., Jadhav, M. M., Naga Ramesh, J. V., & Muniyandy, E. (2024). Secure Communications with THz Reconfigurable Intelligent Surfaces and Deep Learning in 6G Systems. *Wireless Personal Communications*, 1-17.
19. Thepade, D. S., Mandal, P. R., & Jadhav, S. (2015). Performance Comparison of Novel Iris Recognition Techniques Using Partial Energies of Transformed Iris Images and Enegy CompactionWith Hybrid Wavelet Transforms. In *Annual IEEE India Conference (INDICON)*.

20. Vandana, C. P., Basha, S. A., Madiajagan, M., Jadhav, S., Matheen, M. A., & Maguluri, L. P. (2024). IoT resource discovery based on multi faected attribute enriched CoAP: smart office seating discovery. *Wireless Personal Communications*, 1-18.
21. Jadhav, S., Durairaj, M., Reenadevi, R., Subbulakshmi, R., Gupta, V., & Ramesh, J. V. N. (2024). Spatiotemporal data fusion and deep learning for remote sensing-based sustainable urban planning. *International Journal of System Assurance Engineering and Management*, 1-9.
22. Jadhav, S., Chaudhari, V., Barhate, P., Deshmukh, K., & Agrawal, T. (2021). Extreme Gradient Boosting for Predicting Stock Price Direction in Context of Indian Equity Markets. In *Intelligent Sustainable Systems: Selected Papers of WorldS4 2021, Volume 2* (pp. 321-330). Singapore: Springer Nature Singapore.
23. Jadhav, S., Chaudhari, V., Barhate, P., Deshmukh, K., & Agrawal, T. (2021). REVIEW PAPER ON: ALGORITHMIC TRADING USING ARTIFICIAL INTELLEGENCE.
24. Jadhav, S., Chaudhari, V., Barhate, P., Deshmukh, K., & Agrawal, T. (2021). in Context of Indian Equity Markets. *Intelligent Sustainable Systems: Selected Papers of WorldS4 2021, Volume 2*, *334*, 321.
25. Jadhav, S. R., Bishnoi, A., Safarova, N., Khan, F., Aurangzeb, K., & Alhussein, M. (2024). Dual-Attention Based Multi-Path Approach for Intensifying Stock Market Forecasting. *Fluctuation and Noise Letters*, *23*(02), 2440009.
26. Vishwanath, B., & Vaddepalli, S. (2023). The future of work: Implications of artificial intelligence on hr practices. *Tuijin Jishu/Journal of Propulsion Technology*, *44*(3), 1711-1724.
27. Surendar Vaddepalli, D. B. V. (2025). ENTREPRENEURIAL ECOSYSTEMS IN THE GCC-ASSESSING SUPPORT SYSTEMS FOR WOMEN AND DISABLED ENTREPRENEURS IN OMAN. *Machine Intelligence Research*, *19*(1), 126-143.
28. Vaddepalli, S., & Vishwanath, B. (2024). MERGERS AND ACQUISITIONS: DRIVERS, CHALLENGES, AND PERFORMANCE OUTCOMES IN GCC NATIONS. *International Journal of Central Banking*, *20*(1), 298-310.
29. Sangam, V. G., Priyadarshini, S. H., Anand, N., Prathibha, P., Purohit, P., & Nalamitha, R. (2021, June). Early Detection of Diabetic Foot Ulcer. In *Journal of Physics: Conference Series* (Vol. 1937, No. 1, p. 012049). IOP Publishing.
30. Kumar, C. R., Vijayalakshmi, B., Priyadarshini, S. H., Sikdar, S., Bhat, S. N., & Neelam, M. (2020). Standing wheelchair with voice recognition system. *J. Crit. Rev*, *7*, 2042-2047.
31. Priyadarshini, S. H., Dutt, D. N., & Rajan, A. P. (2019). Nonlinear Processing of Wrist Pulse Signals to Distinguish Diabetic and Non-Diabetic Subjects. *Int. J. Eng. Adv. Technol.*, *9*(1), 7105-7110.
32. Priyadarshini, S. H., Poojitha, S., Vinay, K. V., & VA, A. D. (2023, October). AQUASENSE: Sensor Based Water Quality Monitoring Device. In *2023 International Conference on Self Sustainable Artificial Intelligence Systems (ICSSAS)* (pp. 1786-1789). IEEE.
33. Padma, C. R., Priyadarshini, S. H., Nanditha, H. G., Pavithra, G., & Manjunath, T. C. (2022, August). Design & Development of micro-controlled system using VHDL with the help of UART Tx & Rx. In *2022 2nd Asian Conference on Innovation in Technology (ASIANCON)* (pp. 1-11). IEEE.
34. Rao, M. R., Mangu, B., & Kanth, K. S. (2007, December). Space vector pulse width modulation control of induction motor. In *IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007)* (pp. 349-354). Stevenage UK: IET.
35. Rao, M. R., & Prasad, P. V. N. (2014). Modelling and Implementation of Sliding Mode Controller for PMBDC Motor Drive. *International journal of advanced research in electrical, electronics and instrumentation engineering*, *3*(6).
36. Sameera, K., & MVR, S. A. R. (2014). Improved power factor and reduction of harmonics by using dual boost converter for PMBLDC motor drive. *Int J Electr Electron Eng Res*, *4*(5), 43-51.
37. Srinivasu, B., Prasad, P. V. N., & Rao, M. R. (2006, December). Adaptive controller design for permanent magnet linear synchronous motor control system. In *2006 International Conference on Power Electronic, Drives and Energy Systems* (pp. 1-6). IEEE.
38. Al-Ghanimi, M. G., Hanif, O., Jain, M. V., Kumar, A. S., Rao, R., Kavin, R., ... & Hossain, M. A. (2022, December). Two TS-Fuzzy Controllers based Direct Torque Control of 5-Phase Induction Motor. In *2022 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)* (pp. 1-6). IEEE.
39. Prathap, P. B., & Saara, K. (2024). Quantifying efficacy of the fiber bragg grating sensors in medical applications: a survey. *Journal of Optics*, *53*(5), 4180-4201.
40. Kumar, T. V. (2024). A Comprehensive Empirical Study Determining Practitioners' Views on Docker Development Difficulties: Stack Overflow Analysis.
41. Kumar, T. V. (2024). A New Framework and Performance Assessment Method for Distributed Deep Neural NetworkBased Middleware for Cyberattack Detection in the Smart IoT Ecosystem.

42. Arora, P., & Bhardwaj, S. (2017). A Very Safe and Effective Way to Protect Privacy in Cloud Data Storage Configurations.
43. Arora, P., & Bhardwaj, S. (2017). Combining Internet of Things and Wireless Sensor Networks: A Security-based and Hierarchical Approach.
44. Arora, P., & Bhardwaj, S. (2017). Enhancing Security using Knowledge Discovery and Data Mining Methods in Cloud Computing.
45. Yendluri, D. K., Ponnala, J., Tatikonda, R., Kempanna, M., Thatikonda, R., & Bhuvanesh, A. (2023, November). Role of rpa & ai in optimizing network field services. In *2023 7th International Conference on Computation System and Information Technology for Sustainable Solutions (CSITSS)* (pp. 1-6). IEEE.
46. Yendluri, D. K., Ponnala, J., Thatikonda, R., Kempanna, M., Tatikonda, R., & Bhuvanesh, A. (2023, November). Impact of Robotic Process Automation on Enterprise Resource Planning Systems. In *2023 International Conference on the Confluence of Advancements in Robotics, Vision and Interdisciplinary Technology Management (IC-RVITM)* (pp. 1-6). IEEE.
47. Sidharth, S. (2021). MULTI-CLOUD ENVIRONMENTS: MITIGATING SECURITY RISKS IN DISTRIBUTED ARCHITECTURES.
48. Sidharth, S. (2020). THE GROWING THREAT OF DEEPFAKES: IMPLICATIONS FOR SECURITY AND PRIVACY.
49. Sidharth, S. (2019). QUANTUM-ENHANCED ENCRYPTION TECHNIQUES FOR CLOUD DATA PROTECTION.
50. Sidharth, S. (2019). SECURING CLOUD-NATIVE MICROSERVICES WITH SERVICE MESH TECHNOLOGIES.
51. Sidharth, S. (2019). DATA LOSS PREVENTION (DLP) STRATEGIES IN CLOUD-HOSTED APPLICATIONS.
52. Sidharth, S. (2018). RANSOMWARE TRENDS AND EFFECTIVE MITIGATION TECHNIQUES IN 2018.
53. Sidharth, S. (2018). POST-QUANTUM CRYPTOGRAPHY: PREPARING FOR A QUANTUM COMPUTING ERA.
54. Sidharth, S. (2017). CYBERSECURITY STRATEGIES FOR IOT DEVICES IN SMART CITIES.
55. Sidharth, S. (2017). ACCESS CONTROL MODELS FOR SECURE HYBRID CLOUD DEPLOYMENT.
56. Sidharth, S. (2017). MACHINE LEARNING ALGORITHMS FOR REALTIME MALWARE DETECTION.
57. Ara, T., Ambareen, J., Venkatesan, S., Geetha, M., & Bhuvanesh, A. (2024). An energy efficient selection of cluster head and disease prediction in IoT based smart agriculture using a hybrid artificial neural network model. *Measurement: Sensors*, *32*, 101074.
58. Divyashree, H. S., Avinash, N., Manjunatha, B. N., Vishesh, J., & Mamatha, M. (2024). Enhancing secrecy using hybrid elliptic curve cryptography and Diffie Hellman key exchange approach and Young's double slit experiment optimizer based optimized cross layer in multihop wireless network. *Measurement: Sensors*, *31*, 100967.
59. NR, D., GK, D. S., & Kumar Pareek, D. P. (2022, February). A Framework for Food recognition and predicting its Nutritional value through Convolution neural network. In *Proceedings of the International Conference on Innovative Computing & Communication (ICICC)*.
60. Prasath, D. S., & Selvakumar, A. (2015). A Novel Iris Image Retrieval with Boundary Based Feature Using Manhattan Distance Classifier. *International Journal Of Innovative Technology And Creative Engineering (Issn: 2045-8711) Vol*, *5*.
61. Nirmala, K., & Prasath, S. (2020). Probabilistic mceliece public-key cryptography based identity authentication for secured communication in VANET. *Solid State Technology*, *63*(6), 10167-10182.
62. Sivasankaran, P., & Dhanaraj, K. R. (2024). Lung Cancer Detection Using Image Processing Technique Through Deep Learning Algorithm. *Revue d'Intelligence Artificielle*, *38*(1).
63. Pannirselvam, S., & Prasath, S. (2015). A Novel Technique for Face Recognition and Retrieval using Fiducial Point Features. *Procedia Computer Science*, *47*, 301-310.
64. Tamilselvi, R., Mohanasathiya, K. S., & Prasath, S. (2024). Developed a Smooth Support Vector Machine to Predict the Crop Production in Alluvial Soil and Red Soil Regions of Tamil Nadu India [J]. *Naturalista Campano*, *28*(1), 279-297.