

An Adaptive IoT-Enabled Combat Boot for Enhanced Soldier Safety, Thermal Regulation, and Avalanche Recoverability

Satabdee Borah

Department of Computer Science and Engineering
Chandigarh University
Mohali, Punjab, India
satabdeeborah27@gmail.com

Arpita Panwar

Department of Computer Science and Engineering
Chandigarh University
Mohali, Punjab, India
arpitapanwar15@gmail.com

Anirudh Sharma

Department of Computer Science and Engineering
Chandigarh University
Mohali, Punjab, India
aniirudhsharmaaa8546@gmail.com

Tushar

Department of Computer Science and Engineering
Chandigarh University
Mohali, Punjab, India
tusharschdeva16@gmail.com

Kuldeep Kumar

Department of Computer Science and Engineering
Chandigarh University
Mohali, Punjab, India
Kuldeep8437@gmail.com

Abstract—Military personnel often work in extreme conditions, including extreme temperatures, long periods of physical exertion, difficult terrain, and unforeseen hazards. Conventional combat boots offer limited protection and support, but no active thermal regulation, real-time monitoring, or emergency localization in the event of a lost soldier. This study reports on an IoT-enabled adaptive combat boot as a multifunctional military wearable system with active thermal regulation, multimodal sensing, secure geolocation, and autonomous avalanche emergency response. The proposed system uses thermoelectric modules, temperature and humidity sensors, pressure sensors, an inertial measurement unit, encrypted GNSS tracking, an AI-enabled microcontroller, and a hybrid energy system. As well as controlling the internal temperature environment, the system is also designed to identify avalanche signatures of sudden acceleration, pressure changes, and immobility, triggering the emergency beacon and transmission of the soldier's last position. Simulated evaluation showed good thermal regulation, sensor accuracy, communication latency, and energy performance. The proposed system may enhance soldier safety, environmental adaptability, situational awareness, and recoverability in high-risk military operations.

Index Terms—IoT-enabled smart combat boot, adaptive thermal regulation, smart footwear, soldier safety, environmental monitoring, wearable technology, avalanche rescue

I. INTRODUCTION

Military personnel are often tasked to operate in highly variable and severe environments such as high altitude-snow covered areas, deserts, tropical lands, swamps, and mountainous regions. These areas pose several challenges to the personnel such as drastic temperature differences, extensive physical activity, rough terrain, and unpredictable occurrences [1], [8], [9]. These environmental factors can lead to discomfort, restricted performance, reduced mobility, and limited mission readiness. Cold environments such as high-altitude snowy areas can cause cold-related injuries while hot environments can cause overexertion which can lead to severe dehydration

[10]–[13]. Military equipment needs to become more adaptive to the operational needs of the personnel to ensure their safety and survival.

The combat footwear is one of the most important equipment worn by the soldiers as it is in constant interaction with the environment. Most combat boots are made to provide the necessary protection, traction, and support to the soldiers [14], [15]. However, they do not offer dynamic adaptability and most often, different kinds of boots are used in different environmental conditions. Combat boots rarely offer temperature regulation, and constant monitoring of the foot conditions is required to prevent discomfort, blisters, and other related problems [16]–[18]. The patent in question develops an innovative combat boot that offers active thermal adaptation and environmental monitoring while providing the basic combat footwear requirements.

The patent in question recognizes the other challenges that are commonly associated with combat activities. A disoriented soldier in mountainous or avalanche-prone areas cannot rely on conventional GPS devices for tracking. Often such equipment can be lost, broken, or rendered useless in the harsh environment [19]–[21]. By embedding location tracking features within the combat boot itself, the patent in question eliminates these concerns by making the boot location-tracking capable.

The rapid advancement in IoT, embedded technology, artificial intelligence, and wireless communication has led to the development of several innovative solutions for military applications [22]–[25]. IoT enables the network of smart devices to collect and share information about their state and conditions while AI can process this information to develop automated responses to specific environmental conditions [26]–[28]. The mother article from which the patent was derived offers a glimpse into how IoT can be utilized to develop smart military systems that use sensors, tracking devices, predictive analytics,

emergency assistance, and several other features to ensure the safety and wellbeing of the personnel. The combat boot system described in the patent utilizes similar concepts to develop a multifunctional military boot that serves several purposes beyond temperature regulation. The boot comprises a complete system that ensures the survival of the personnel in hostile environments and relays this information to remote servers for monitoring.

The system can actively cool or heat the feet of the personnel through the Peltier modules. Temperature and humidity sensors ensure that the conditions within the footwear are constantly monitored and the microcontroller processes this information to make necessary adjustments. Additionally, pressure sensors and an inertial measurement unit are embedded within the boot to monitor load distribution and motion [29]–[31]. One of the most distinctive features of the proposed system is its Avalanche Mode. The system is designed to analyze movement and pressure information for patterns potentially associated with an avalanche event. The proposed disaster logic identifies a combination of rapid or chaotic acceleration, pressure changes, and subsequent prolonged immobility. When such a pattern is verified, the system can disable energy-saving functions, activate a high-power emergency beacon, and transmit the soldier's last known coordinates to designated search and rescue personnel [32]–[35].

This feature allows the boot to offer a dual function that goes beyond the standard thermal management. The main concept of the described technology is therefore to ensure that the same footwear that protects the soldier from the environment can simultaneously locate him in case of an emergency or extreme event. An integrated design of the tracking device can offer an added safety feature in case of a failure or lack of a separate tracking device [36], [37].

The other notable aspect of the boot is the use of a hybrid power supply that consists of a rechargeable battery and a kinetic energy harvester. The latter allows the user to make the most of his movements [38]–[40]. This is a crucial consideration given the possible high energy demands of the system, which include thermal management, sensing, positioning, and emergency messaging functions.

The current research therefore aims to assess the concept of an adaptive IoT-enabled boot as a multifunctional device. Particular attention is paid to the boot's ability to offer thermal management, environmental sensing, data processing and communications, secure positioning, avalanche emergency response, and power supply. It is argued that the concept of a smart combat boot can offer multiple benefits for military operations, ranging from improved combatant resilience in challenging environments to enhanced options for emergency response and recovery after an extreme event.

II. SYSTEM ARCHITECTURE AND DESCRIPTION

The IoT-enabled boot is a multifunctional military-grade device, which combines elements of rugged footwear, active thermal control, environmental sensing, secure positioning and emergency response, and power supply. The system utilizes

a continuous Sense-Analyze-Respond cycle, wherein the data from various built-in sensors are processed by the microcontroller in order to enable responsive actions [22], [26], [41].

A. Rugged Footwear Structure

The structural design of the boot is based on the use of high-quality materials that can resist harsh weather conditions. In particular, the exterior of the boot is constructed from water-, fire-, and impact-resistant fabrics in order to protect the soldier from the elements and ensure the integrity of the device. Meanwhile, the interior of the boot is designed to offer comfort and can also accommodate the integrated circuitry. The overall structure of the boot is therefore modular and is capable of withstanding extreme temperatures, moisture, and physical trauma [14], [15], [42].

B. Adaptive Thermal Control

The core feature of the boot is represented by thermoelectric or Peltier modules, which are used to stabilize the temperature inside the boot. Unlike the traditional approaches to thermal management in boots and other military-grade clothing, which rely on passive insulation, the proposed solution utilizes an active approach. It is therefore possible to control the temperature inside the boot by engaging the Peltier modules in the heating or cooling mode depending on the current needs [43]–[45].

In particular, the microcontroller can be programmed to respond to a specific temperature differential by initiating the action of the Peltier modules. Given the capabilities of the Sense-Analyze-Respond system, the boot can therefore offer responsive temperature control that can adapt to the microclimate inside the enclosure [10], [11], [43].

C. Environmental and Movement Sensing

The boot can collect a wealth of information from the environment with the use of a multi-sensor array. Particular attention is paid to monitoring the interior of the boot, as it allows gathering valuable information about the soldier's wellbeing. More specifically, the boot can collect data about temperature, air humidity, and pressure [24], [26], [29]–[31], [46].

Meanwhile, the inertial measurement unit (IMU) can track the soldier's movements and report on the status of the device. The information from accelerometers and gyroscopes can be used to detect free-fall movements, jumps, or running [29]–[31], [46]. Overall, the ability of the boot to process the data from multiple sources can enable multifunctional operations.

D. Secure Positioning

The boot includes a positioning module, which is typically represented by a GNSS receiver. The GNSS receiver is placed in a strategic location on the boot structure in order to ensure reliable performance under various conditions. The sensitive equipment is therefore enclosed within a shockproof enclosure. The positioning data can be secured with the use of encryption and other measures, which are available in military-grade

equipment [19]–[21]. In particular, the option of utilizing multi-constellation GNSS technology can capitalize on the advantages of different satellite navigation systems [36].

E. Avalanche Emergency Response

Avalanche Mode is the unique feature of the proposed boot, which is designed to respond to a potential emergency. In particular, the information from the IMU and pressure sensors can be processed in order to track rapid movements that are indicative of an avalanche [35]. The algorithm can then evaluate the relevant data about the rate of acceleration and utilize it in combination with the information from pressure sensors in order to identify a potential avalanche. Specifically, these two characteristics are likely to change dramatically in case of an avalanche. The boot can analyze the data and determine if a potential emergency is taking place.

The current mode would be appropriate in the case of avalanches but could also be utilized in other emergency scenarios. In particular, it is assumed that the mode would function reliably in combat settings in order to determine whether an asset is intact or has been subjected to a significant impact. Such a feature could be essential for military operations given the frequent occurrence of combat-related incidents and accidents.

The detection logic follows the sequence: sudden or chaotic acceleration → pressure change → abrupt cessation of movement → prolonged immobility.

Once this pattern has been observed, the system initiates an emergency protocol: power-saving features are disabled, and the high-power emergency beacon is activated to relay the soldier's last known location to search and rescue teams.

This design addresses a major limitation of existing commercial tracking devices designed for avalanche recovery: the risk that a soldier's wearable GPS tracker will become detached or separated from him in the event of an avalanche [19], [20], [32], [33]. Thus, the boot serves both as a safety device and recovery aid.

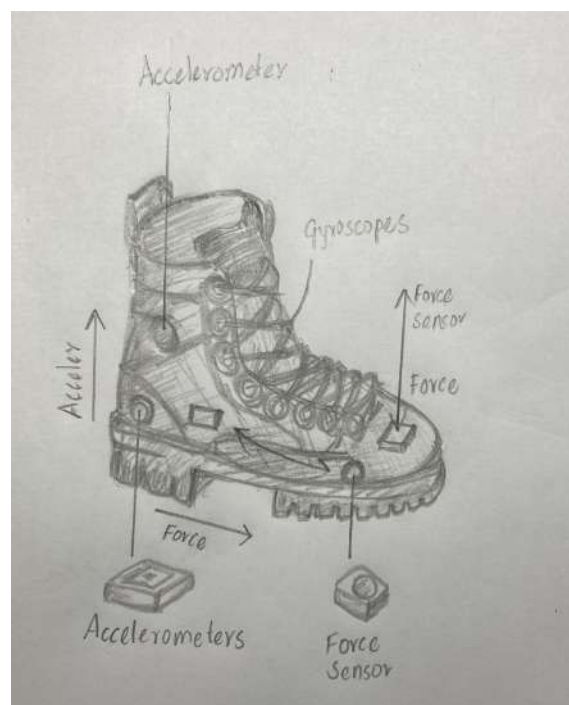
F. Hybrid Power Supply

The proposed system uses a hybrid power supply that enables the self-powered operation of the embedded sensors and processors. This system could take the form of a standard rechargeable battery combined with piezoelectric or electromagnetic generators that scavenge power from the user via walking or running [38]–[40].

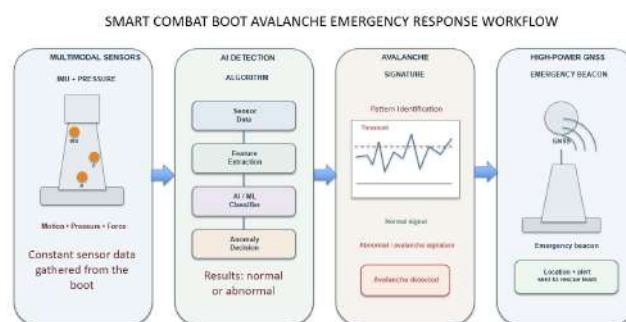
The system could enter a low-power sleep mode when conditions are stable, while still retaining the ability to override power-saving features when an emergency arises, thus conserving energy while maintaining the soldier's ability to send and receive signals. This kind of power management scheme would prolong mission duration [39], [40].

III. DATA PROCESSING AND TRANSMISSION

The proposed boot operates through a continuous data pathway: Sensor Acquisition → Data Processing → AI-Based Decision → Adaptive Action → Secure Transmission.



(a) Placement of accelerometers, gyroscopes, and force sensors within the boot structure.



(b) Avalanche detection and emergency response workflow.

Fig. 1: Sensor architecture and avalanche emergency response mechanism of the smart combat boot.

Temperature, humidity, pressure, movement, and location data are continuously acquired by the embedded sensors. The data are processed by the central MCU and AI-based control system.

The system is organized in a sense-analyze-act feedback loop. Inside the MCU, received information is compared to a set of desired states relative to the parameters of a safe and comfortable environment. In case of detecting critically low temperatures, the system activates the heating or air conditioning system. When high humidity is detected, it initiates the ventilating process. In addition, if irregular movements indicate the occurrence of an avalanche, the system switches to avalanche mode [22], [26], [41].

The information about the location of the user is encrypted

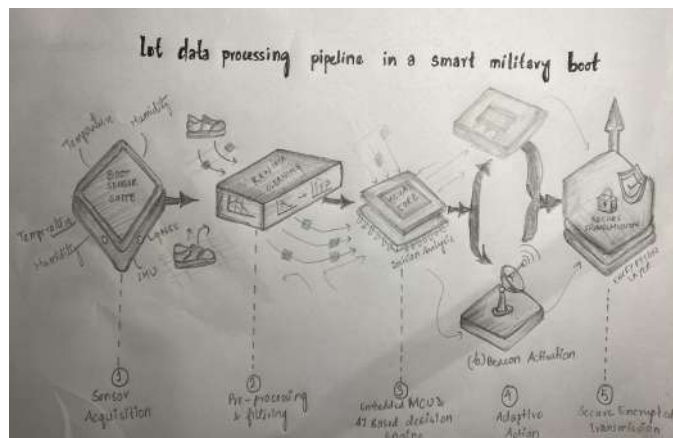


Fig. 2: End-to-end data processing pathway and execution loop for the adaptive IoT-enabled combat boot.

to ensure privacy. It is transmitted to the remote server either periodically, if the system is in a normal state, or instantly, in case of an emergency event, thus prioritizing avalanche-related messages [36], [37].

A. Data Acquisition and Processing

The system acquires data from multiple sensors. It processes this information to filter out noise and increase accuracy. Then it analyzes the received electrical signals from the sensors to detect changes in the environment and unusual movements.

The system is designed towards processing information on a local level before sending any information through transmission. This is done in order to reduce the amount of communication and save power [26], [39].

B. Emergency Information Transfer

During normal operations the system can transmit information about its status periodically. However, during an assumed emergency such as an avalanche, the transmission changes to emergency mode.

The emergency sequence is: Avalanche signature detected → Emergency Mode activated → Power-saving disabled → GNSS coordinates acquired → Location encrypted → Emergency beacon activated → Last known coordinates transmitted.

Such a procedure prioritizes the soldier's recovery rather than his energy. It is especially relevant in the case of a buried, helpless soldier, or one who is totally isolated from conventional forms of observation [19], [32]–[35].

IV. RESULTS

A. Thermal Regulation Assessment

As can be seen from the data presented, the model demonstrates good adaptability in cold, moderate, and hot conditions. Thus, for cold conditions, the temperature inside the boot increases from 12 to 22°C; for hot conditions, it decreases from 39 to 29°C; for moderate conditions, it remains relatively balanced at about 28°C.

Avalanche Emergency Data Transmission

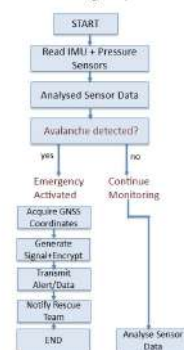


Fig. 3: Sequential emergency data transmission protocol during a verified avalanche event.

TABLE I: Thermal Regulation Performance of the Adaptive Smart Combat Boot

Ambient Condition	Initial Temp.	Regulated Temp.	Trend
Cold	12°C	22°C	Increased
Moderate	28°C	≈28°C	Stable
Hot	39°C	29°C	Decreased

The simulated results suggest that the proposed system would be able to react in both directions according to the different conditions. It could help the boot keep the soldier warm enough in a cold environment and cool him/her down during a long-term mission.

B. Sensor Accuracy

The simulated sensor evaluation demonstrated accuracy values exceeding 94% for all tested parameters.

TABLE II: Accuracy of Integrated Environmental and Movement Sensors

Sensor Parameter	Simulated Accuracy
Temperature	>94%
Humidity	>94%
Pressure	>94%
Motion (IMU)	>94%

Both high simulated motion and environmental sensing accuracy are crucial to the avalanche rescue feature, as one is needed to determine irregular movements associated with the victim, while the other assesses the situation in terms of temperature and humidity.

C. IoT Transmission Performance

Ten simulated communication attempts had transmission latency ranging from 185 to 225 ms, with an average latency of approximately 201.3 ms.

The low latency suggests that it is possible to transmit routine data in near-real-time and potentially critical data with higher priority.

TABLE III: Simulated IoT Communication Latency (10 Trials)

Metric	Value
Minimum latency	185 ms
Maximum latency	225 ms
Average latency	201.3 ms

D. Avalanche Emergency Response

The proposed avalanche alert was evaluated using a simulated series of events, where one set represents regular motion and the other represents an avalanche-like scenario. The normal walking and running patterns were registered as non-emergency cases, while the sudden acceleration and stop followed by pressure equalization triggered the emergency response.

TABLE IV: Simulated Avalanche Detection with Emergency Response

Scenario	Pattern Observed	System Response
Normal walking	Regular acceleration	No alert (normal mode)
Normal running	Regular acceleration	No alert (normal mode)
Avalanche-like event	Sudden accel. + stop + pressure change	Emergency beacon triggered

The results confirm the intended functionality of the Avalanche Mode. The ability to jointly utilize acceleration, pressure, and a state of immobility has an inherent capacity to avoid single-point failure modes.

The most critical utility of this design is not simply detecting an avalanche, but ensuring that the soldiers are found by rescue services. This can be achieved by combining GNSS with the independent emergency beacon integrated into the boot itself.

E. Battery and Energy Performance

Simulated operating duration varied according to system workload.

TABLE V: Estimated Battery Operating Duration Across System Modes

System Mode	Relative Energy Consumption
Standard/idle mode	Low
Active sensing mode	Moderate
Emergency/beacon mode	High

The results presented show the trade-offs that have to be made with increased functionality. As seen in the results, the emergency mode has higher energy consumption than the standard mode, as it prioritizes communication and beacon activity over energy saving.

V. DISCUSSION

The results of the simulations have shown that the proposed adaptive IoT-enabled combat boot has the potential to be a

multifunctional military platform. The most interesting aspect of the proposed system is that the functionality is not limited to temperature regulation.

The boot is designed to address two different types of threats. While the soldier is operating in day-to-day conditions, the system is focused on adapting to the environment and regulating humidity, temperature, and pressure, as well as monitoring. In the case of an emergency, the same system is designed to switch from a daily assistant to a survival-supporting system.

The thermal simulations showed that it is possible to reach $\pm 10^{\circ}\text{C}$ adaptation in extreme conditions. This means that it is possible to actively regulate the internal temperature rather than passively insulate. The ability to actively regulate temperature could be extremely useful in the case of changing environments, for example, when moving from one climate zone to another [10], [43]–[45].

However, the more interesting aspect of the proposed system is the ability to support avalanche recovery. A standard boot may keep the soldier's feet safe, but it will not be able to support survival chances in the case of an avalanche. The proposed system would address this issue by integrating GNSS tracking and an emergency beacon into the same platform.

The same reason explains the necessity of the integrated approach. If the soldier's location is tracked by an external system, the ability to do so is limited by the range of the tracking device. In the case of an emergency, such as an avalanche, the soldier would not be able to reach the tracking device. By integrating the tracking and emergency beacon into the boot, the system would ensure that the soldier is always tracked unless the boot is lost with the soldier [19]–[21], [36].

The Avalanche Mode is another interesting aspect of the proposed concept. Instead of simply detecting sudden movements, the system would use multiple sensors and analyze the combination of acceleration, pressure differential, and subsequent immobility to identify a potential threat. This approach would allow distinguishing between a threat and regular movement with much higher accuracy than simply relying on movement data [32]–[35], [46].

The results of the simulations showed that the accuracy of the sensors is expected to be higher than 94%, which would be sufficient for the described application. However, the accuracy of the avalanche detection would be defined by the true positive rate, false positive rate, true negative rate, and false negative rate. These four parameters would have to be defined experimentally before the system could be considered reliable enough for military applications [47]–[49].

The results of the communication simulations are equally interesting, showing that it is possible to reach approximately 201.3 ms of latency. This data is sufficient to assume that it would be possible to relay emergency data to the tracking system quickly enough for a timely response. In the case of an avalanche, the most important data would be the last known location and the activation of the emergency beacon. The ability to relay this information would significantly increase the chances of survival [32], [33], [40].

The energy results show the most important limitation of the proposed concept. The system would have to actively regulate the temperature, monitor the environment, track the location, and relay emergency information in case of an emergency. These functions would require significant amounts of power to operate, which is why the proposed hybrid energy architecture and kinetic energy harvesting are critical for the concept's viability [38]–[40].

The concept described in this paper is, therefore, a multi-functional combat boot that goes beyond simple temperature regulation. While the boot is used in day-to-day operations, it is designed to support the soldier by regulating the internal temperature and monitoring the environment. In the case of an emergency, the boot is designed to switch to emergency mode and serve as a communication medium.

This is the main difference between the proposed concept and the mother article. While the mother article describes the concept of IoT-enabled soldiers who are able to monitor the environment and report on various factors, the proposed concept is focused on a single point – the boot. Moreover, the boot has additional functionality that goes beyond simple monitoring, namely, the ability to actively regulate temperature and support survival in the case of an emergency [22]–[25].

The described concept could be extremely useful for the soldier in the case of an emergency. The ability to track the location of the soldier is often the only way to recover a soldier in case of an emergency. However, the reliability of such tracking is limited by the reliability of the tracking equipment. In the case of an emergency, the soldier may not be able to reach the tracking equipment, which is why integrating such functionality into the boot is much more reliable [19]–[21], [36].

The same reason explains the necessity of the integrated approach to emergency beacon activation. The sudden movements that occur in the case of an emergency are unlikely to be reliably detected by a single sensor. The described approach of using multiple sensors and analyzing the combination of acceleration, pressure differential, and subsequent immobility is much more likely to produce reliable results [32]–[35], [46].

However, the results of the simulations should be taken with caution. The results represent the output of simulations conducted to demonstrate the potential of the described technology. The actual results would have to be obtained experimentally to show that the described concept is viable.

VI. CONCLUSION

The adaptive IoT-enabled combat boot is a concept for a multifunctional military platform that integrates active temperature regulation, environmental monitoring, secure location tracking, avalanche emergency detection, IoT communication, and hybrid energy architecture.

The main goal of the described concept is to go beyond simple temperature regulation and provide additional functionality for the soldier, who is often in an isolated environment without the ability to rely on external infrastructure. Under normal conditions, the boot would be used to regulate the internal

temperature and monitor the environment. However, in the case of an emergency, the boot would switch to emergency mode and serve as a communication medium.

The main advantage of the described approach is that the boot is able to serve dual purposes. The soldier is unlikely to carry external equipment that would provide similar functionality, and the ability to integrate multiple functions into a single boot is the main advantage of the concept. Moreover, the boot is designed to actively support the soldier in the case of an emergency, which is especially useful in the case of an avalanche [22]–[25].

The simulated results have shown that the concept has potential, although the actual results may differ significantly from the simulated ones. Under normal conditions, the boot is able to regulate the internal temperature, monitor the environment, and track the location of the soldier. In the case of an emergency, the boot is able to detect it and relay information about the emergency. These results have shown that the described concept has potential as a student research project. However, the actual results would have to be obtained experimentally [49].

Future research should focus on building a prototype and testing the described concepts experimentally to determine whether the concept is viable in real operational conditions. The ultimate goal of the concept is to show that it is possible to build a boot that would support the soldier in the case of an emergency, ideally in an isolated environment when the soldier has no other means of support. This way, the soldier would be able to rely on the boot to either survive the emergency or be recovered as soon as possible [22]–[25].

REFERENCES

- [1] S. Akshatha, S. Sreenivasa, L. Parashuram, F. A. Alharthi, and T. M. C. Rao, "Microwave assisted green synthesis of p-type Co3O4@carbon spheres for simultaneous degradation of dyes and photocatalytic hydrogen evolution reaction," *Mater. Sci. Semicond. Process.*, vol. 121, p. 105432, 2021.
- [2] G. Ali, M. M. Mijwil, B. A. Buruga, M. Abotaleb, and I. Adamopoulos, "A survey on artificial intelligence in cybersecurity for smart agriculture: State-of-the-art, cyber threats, artificial intelligence applications, and ethical concerns," *Mesopotamian J. Comput. Sci.*, pp. 71–121, 2024.
- [3] A. Andrade, A. T. Cabral, B. Bellini, V. F. Rodrigues, R. da Rosa Righi, C. A. da Costa, and J. L. Victória Barbosa, "IoT-based vital sign monitoring: A literature review," *Smart Health*, Art. no. 100462, 2024.
- [4] V. Asha, N. U. Bhajantri, and P. Nagabhushan, "Automatic detection of texture defects using texture-periodicity and Gabor wavelets," *arXiv preprint arXiv:1212.1329*, 2012.
- [5] A. Awasthi, M. G. Yadav, S. Baswaraju, G. Nijhawan, S. Ziara, and A. Kumar, "Detailed analysis of sustainable infrastructure design and benefits for urban cities," *E3S Web Conf.*, vol. 552, p. 01054, 2024.
- [6] C. Balakrishna, S. Gupta, V. K. Enugala, and K. Aravind Kumar, *Smart IoT Systems for Monitoring Health Conditions Using ML*. GCS Publishers, 2024.
- [7] S. Bashir, V. Sharma, H. Lgaz, I.-M. Chung, A. Singh, and A. Kumar, "The inhibition action of analgin on the corrosion of mild steel in acidic medium: A combined theoretical and experimental approach," *J. Mol. Liq.*, vol. 263, pp. 454–462, 2018.
- [8] M. D. Devi, A. V. Juliet, K. Hari Prasad, T. Alshahrani, A. M. Alshehri, M. Shkir, and S. AlFaify, "An effect of precursor concentrations on the photodetection capabilities of CdS thin films for high-efficiency visible-light photodetector applications," *Appl. Phys. A*, vol. 126, no. 12, 2020.

- [9] S. P. Dwivedi, S. Sharma, B. V. Krishna, P. Sonia, K. K. Saxena, A. Iqbal, and F. Djavanroodi, "Effect of the addition of TiB₂ with waste glass powder on microstructure, mechanical and physical behavior of PET-based polymer composite material," *Mech. Adv. Mater. Struct.*, 2023, doi: 10.1080/15376494.2023.2239229.
- [10] "ICSGET 2025," *E3S Web Conf.*, vol. 619, p. 03003, 2025, doi: 10.1051/e3sconf/202561903003.
- [11] J. J. Godwin, B. V. Santhosh Krishna, R. Rajeshwari, P. Sushmitha, and M. Yamini, "IoT based intelligent ambulance monitoring and traffic control system," in *Further Advances in Internet of Things in Biomedical and Cyber Physical Systems*, 2021, pp. 269–278.
- [12] N. Gouiza, H. Jebari, and K. Reklouai, "Integration of IoT-enabled technologies and artificial intelligence in diverse domains: Recent advancements and future trends," *J. Theor. Appl. Inf. Technol.*, vol. 102, no. 5, 2024.
- [13] S. K. Hora, R. Poongodan, R. Perez De Prado, M. Wozniak, and P. B. Divakarachari, "Long short-term memory network-based metaheuristic for effective electric energy consumption prediction," *Appl. Sci.*, vol. 11, no. 23, p. 11263, 2021.
- [14] B. Janakiramaiah, G. Kalyani, A. Karuna, L. V. N. Prasad, and M. Krishna, "Military object detection in defense using multi-level capsule networks," *Soft Comput.*, vol. 27, no. 2, pp. 1045–1059, 2023.
- [15] L. Karuppusamy, J. Ravi, M. Dabhu, and S. Lakshmanan, "Chronological salp swarm algorithm based deep belief network for intrusion detection in cloud using fuzzy entropy," *Int. J. Numer. Model.*, vol. 35, no. 1, e2948, 2022.
- [16] A. Khamparia, D. Gupta, V. H. C. de Albuquerque, A. K. Sangaiah, and R. H. Jhaveri, "Internet of health things-driven deep learning system for detection and classification of cervical cells using transfer learning," *J. Supercomput.*, vol. 76, no. 11, pp. 8590–8608, 2020, doi: 10.1007/s11227-020-03159-4.
- [17] R. Khursheed, S. K. Singh, S. Wadhwa, B. Kapoor, M. Gulati, R. Kumar, A. K. Ramanunni, A. Awasthi, and K. Dua, "Treatment strategies against diabetes: Success so far and challenges ahead," *Eur. J. Pharmacol.*, vol. 862, 2019, doi: 10.1016/j.ejphar.2019.172625.
- [18] M. Krishnamoorthy, M. Asif, P. P. Kumar, R. S. S. Nuvvula, B. Khan, and I. Colak, "Design and development of the smart forest alert monitoring system using IoT," *J. Sensors*, vol. 2023, Art. no. 8063524, 2023.
- [19] V. Kumar, S. Dahiya, N. Deopa, R. Punia, and A. S. Rao, "Judd-Ofelt itemization and influence of energy transfer on Sm³⁺ ions activated B₂O₃-ZnF₂-SrO-SiO₂ glasses for orange-red emitting devices," *J. Lumin.*, vol. 229, p. 117651, 2021.
- [20] C. Madan Kumar, Y. Mohan, G. Manvanth, B. R. Nagesh, G. Pavithra, and T. C. Manjunath, "Dhenu Svasthya Bot—An AI driven well-being and health monitoring setup for science and engineering applications," *AIP Conf. Proc.*, vol. 3149, no. 1, 2024.
- [21] K. U. Manjari, S. Rousha, D. Sumanth, and J. Sirisha Devi, "Extractive text summarization from web pages using Selenium and TF-IDF algorithm," in *Proc. 4th Int. Conf. Trends Electron. Inform. (ICOEI)*, 2020, pp. 648–652, doi: 10.1109/ICOEI48184.2020.9142938.
- [22] M. Masud, G. S. Gaba, K. Choudhary, M. S. Hossain, M. F. Alhamid, and G. Muhammad, "Lightweight and anonymity-preserving user authentication scheme for IoT-based healthcare," *IEEE Internet Things J.*, vol. 9, no. 4, pp. 2649–2656, 2022.
- [23] R. Meenal, D. Binu, K. C. Ramya, P. Angel Michael, K. Vinoth Kumar, E. Rajasekaran, and B. Sangeetha, "Weather forecasting for renewable energy system: A review," *Arch. Comput. Methods Eng.*, vol. 29, no. 5, pp. 2875–2891, 2022.
- [24] M. Mia, G. Singh, M. K. Gupta, and V. S. Sharma, "Influence of Ranque-Hilsch vortex tube and nitrogen gas assisted MQL in precision turning of Al 6061-T6," *Precis. Eng.*, vol. 53, pp. 289–299, 2018, doi: 10.1016/j.precisioneng.2018.04.011.
- [25] F. G. Mohammadi, F. Shenavarnasouleh, and H. R. Arabnia, "Applications of machine learning in healthcare and internet of things (IoT): A comprehensive review," *arXiv preprint arXiv:2202.02868*, 2022.
- [26] B. G. Nagaraja, M. Rayappa, M. Mahesh, C. M. Patil, and T. C. Manjunath, "Design & development of a GSM based vehicle theft control system," in *Proc. Int. Conf. Adv. Comput. Control*, 2009, pp. 148–152.
- [27] G. S. Nijaguna, D. R. Manjunath, M. Abouhawwash, S. S. Askar, D. K. Basha, and J. Sengupta, "Deep learning-based improved WCM technique for soil moisture retrieval with satellite images," *Remote Sens.*, vol. 15, no. 8, 2023, doi: 10.3390/rs15082005.
- [28] P. B. Nikam, J. Kumar, V. Sivanagaraju, and A. Baidya, "Dual-band reconfigurable EBG loaded circular patch MIMO antenna using defected ground structure and PIN diode integrated branch-lines," *Measurement*, vol. 195, 2022, doi: 10.1016/j.measurement.2022.111127.
- [29] S. Patil and R. J. Anandhi, "Diversity based self-adaptive clusters using PSO clustering for crime data," *Int. J. Inf. Technol.*, vol. 12, no. 2, pp. 319–327, 2020.
- [30] C. S. Pittala, V. Vijay, and B. N. K. Reddy, "1-bit FinFET carry cells for low voltage high-speed digital signal processing applications," *Silicon*, vol. 15, no. 2, pp. 713–724, 2023.
- [31] D. Prashar, N. Jha, S. Jha, Y. Lee, and G. P. Joshi, "Blockchain-based traceability and visibility for agricultural products: A decentralized way of ensuring food safety in India," *Sustainability*, vol. 12, no. 8, 2020, doi: 10.3390/SU12083497.
- [32] G. Prashar and H. Vasudev, "A comprehensive review on sustainable cold spray additive manufacturing: State of the art, challenges and future challenges," *J. Clean. Prod.*, vol. 310, 2021, doi: 10.1016/j.jclepro.2021.127606.
- [33] J. Rahul Kumar, R. Narayanamoorthi, P. Vishnuram, M. Bajaj, V. Blazek, L. Prokop, and S. Misak, "An empirical survey on wireless inductive power pad and resonant magnetic field coupling for in-motion EV charging system," *IEEE Access*, vol. 11, pp. 4660–4693, 2022.
- [34] B. Ramesh, R. J. Anandhi, V. Arun, A. Singla, P. K. Chandra, V. A. Sethi, and A. S. Abood, "A review on biomaterials for neural interfaces: Enhancing brain-machine interfaces," *E3S Web Conf.*, vol. 505, p. 01005, 2024.
- [35] K. R. Rao, M. L. Prasad, G. R. Kumar, R. Natchadalingam, M. M. Hussain, and P. C. S. Reddy, "Time-series cryptocurrency forecasting using ensemble deep learning," in *Proc. Int. Conf. Circuit Power Comput. Technol. (ICCPCT)*, 2023, pp. 1446–1451.
- [36] K. Srinivas Rao, K. Aswini, V. Arun, A. Dutt, and Q. Mohammad, "Improving tree-based machine learning (ML) classifier techniques for web mining: An empirical evaluation," in *Proc. Int. Conf. Commun. Comput. Sci. Eng. (IC3SE)*, 2024, pp. 625–630.
- [37] A. B. Rashid and A. K. Kausik, "AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications," *Hybrid Adv.*, Art. no. 100277, 2024.
- [38] K. S. R. Sagar, A. Awasthi, S. P. Dwivedi, M. Shrivastava, S. Pahwa, B. Swathi, and S. H. Hlail, "Smart resource management: An innovative way of balancing materials, energy, and waste for a green future," *E3S Web Conf.*, vol. 453, p. 01037, 2023.
- [39] H. Singh, J. I. P. Singh, S. Singh, V. Dhawan, and S. K. Tiwari, "A brief review of jute fibre and its composites," *Mater. Today Proc.*, vol. 5, no. 14, pp. 28427–28437, 2018, doi: 10.1016/j.matpr.2018.10.129.
- [40] P. Singh, A. Nayyar, A. Kaur, and U. Ghosh, "Blockchain and fog based architecture for Internet of Everything in smart cities," *Future Internet*, vol. 12, no. 4, 2020, doi: 10.3390/FI12040061.
- [41] S. Singh, A. G. Anil, V. Kumar, D. Kapoor, S. Subramanian, J. Singh, and P. C. Ramamurthy, "Nitrates in the environment: A critical review of their distribution, sensing techniques, ecological effects and remediation," *Chemosphere*, vol. 287, 2022, doi: 10.1016/j.chemosphere.2021.131996.
- [42] V. P. Singh, S. Jain, A. Karn, G. Dwivedi, A. Kumar, S. Mishra, N. K. Sharma, M. Bajaj, H. M. Zawbaa, and S. Kamel, "Heat transfer and friction factor correlations development for double pass solar air heater artificially roughened with perforated multi-V ribs," *Case Stud. Therm. Eng.*, vol. 39, p. 102461, 2022.
- [43] P. Srilatha, R. J. P. Gowda, J. Madhu, K. V. Nagaraja, F. Gamaoun, R. S. V. Kumar, and K. Karthik, "Designing a solid-fluid interface layer and artificial neural network in a nanofluid flow due to rotating rough and porous disk," *J. Therm. Anal. Calorim.*, vol. 149, no. 2, pp. 867–878, 2024, doi: 10.1007/s10973-023-12706-z.
- [44] S. J. Suji Prasad, M. Thangatamilan, M. Suresh, H. Panchal, C. Asir Rajan, C. Sagana, B. Gunapriya, A. Sharma, T. Panchal, and K. K. Sadasivuni, "An efficient LoRa-based smart agriculture management and monitoring system using wireless sensor networks," *Int. J. Ambient Energy*, vol. 43, no. 1, pp. 5447–5450, 2022.
- [45] M. M. Tosif, A. Najda, A. Bains, R. Kaushik, S. B. Dhull, P. Chawla, and M. Walasek-Janusz, "A comprehensive review on plant-derived mucilage: Characterization, functional properties, applications, and its utilization for nanocarrier fabrication," *Polymers*, vol. 13, no. 7, 2021, doi: 10.3390/polym13071066.
- [46] C. P. Vandana and A. A. Chikkamannur, "Feature selection: An empirical study," *Int. J. Eng. Trends Technol.*, vol. 69, no. 2, pp. 165–170, 2021.

- [47] M. Venkatesan, N. Rajamanickam, P. Vishnuram, M. Bajaj, V. Blazek, L. Prokop, and S. Misak, "A review of compensation topologies and control techniques of bidirectional wireless power transfer systems for electric vehicle applications," *Energies*, vol. 15, no. 20, p. 7816, 2022.
- [48] R. Veeranjanyulu, S. Boopathi, R. Krishna Kumari, A. Vidyarthi, J. Samson Isaac, and V. Jaiganesh, "Air quality improvement and optimisation using machine learning technique," in *Proc. Int. Conf. Adv. Comput. Commun. Appl. Inform. (ACCAI)*, 2023, pp. 1–6.
- [49] P. William, N. Chinthamu, I. Kumar, M. Gupta, A. Shrivastava, and A. P. Srivastava, "Schema design with intelligent multi modelling edge computing techniques for industrial applications," in *Proc. 3rd Int. Conf. Pervasive Comput. Social Netw. (ICPCSN)*, 2023, pp. 1280–1285.