

Evaluating the Impact of AI, Machine Learning, and IoT-Based Smart Environmental Monitoring Systems on Ecological Harmony: A Daoist Perspective

R. Saranya¹, Dr Ganesha K S², Dr.Sejal Rahul Trivedi³, Moazzam Haidari⁴,
Dr. Kaushika Pal⁵, Krishna Chandra Patra⁶

¹Assistant Professor, Department of Information Technology, V.S.B. Engineering College, Karur, Tamilnadu ,
Pin Code: 639111, India. Email: saranram202@gmail.com

²Assistant Professor, Department of Management Studies, Dayananda Sagar College of Engineering,
Bangalore, Karnataka, India. Email: ganeshaks@gmail.com

³Assistant professor, Shanti Business School, Ahmedabad, India. Email: seju101ster@gmail.com

⁴Assistant Professor, Department of Electrical Engineering, Saharsa College of Engineering, Saharsa, Bihar,
Pincode: 852201, India. Email: moazzam53211@gmail.com

⁵Department of Computer Applications, Sarvajani College of Engineering and Technology , Surat, Gujarat,
Pincode : 395001, India. Email: kaushika.pal@scet.ac.in

⁶Assistant professor, Department of Mechanical Engineering, Indira Gandhi Institute of Technology,
Sarang, Pincode: 759146, India. Email: kcpmechcvrce@gmail.com

Abstract

Rapidly increasing levels of pollution, variation in climate, consumption of resources and a total disregard for the natural ecological balance have become issues of ever-increasing global concern. Monitoring the environment traditionally has a number of limitations such as a small number of observation points, delayed acquisition of data and the inability to make predictions. This is why Intelligent Environmental Technologies and Smart Eco-Systems have become the cornerstone of efficient ecological management and monitoring on an eco-systemic scale, on the basis of large amounts of information that are acquired in real time and subsequently analyzed by Intelligent Information Processing Systems. A large number of monitoring observation points are equipped with sensors of various types (local and remote) that can continuously monitor environmental parameters (air, water, soil) and transfer them for subsequent analysis in Information Processing Systems. Large amounts of environmental information that are continuously acquired are processed using Artificial Intelligence (AI) and Machine Learning (ML) methods for the purposes of Eco-System monitoring, prediction and the early detection of any disruptions and possible dangers to the Eco-System. This study evaluates the potential of the AI/ML and IoT technologies for environmental monitoring in terms of their contribution to the ecological balance. By conceptual analysis and from system's perspective, this study investigates possible integration between current intelligent environmental technologies and the Daoist philosophical point of view. The expected results from the application of AI and IoT-based environmental monitoring systems to enhance the efficiency of current approaches to environmental monitoring, to improve the accuracy of predictions, and to identify possible ecological disturbances prior to them having a negative impact on the environment. In combination with Daoist principles of natural flow, balance, and non-interference, smart environmental monitoring systems also have the potential to support a more sustainable and also more ethical form of environmental management, which supports and maintains ecological harmony. Thus, by using these advanced technologies in an appropriate manner, ecological balance can be supported in line with Daoist concepts of equilibrium and natural order.

Keywords: *AI, Machine Learning, Internet of Things, Environmental Monitoring, Ecological Harmony, Daoism, Smart Systems.*

1. Introduction

Environmental systems across the globe are experiencing unprecedented stress due to accelerating climate change, increasing levels of air and water pollution, rapid urbanization, industrial expansion, and significant biodiversity loss[1]. These interconnected global environmental problems are producing instability in environmental systems and reducing their natural resilience and ability to function in a sustainable way[2]. The problems facing the Earth's environmental systems require solutions that are able to deal with large scale dynamic problems that have yet to be fully defined[3]. Conventional methods of monitoring the environment using periodic sampling and fixed points of observation are no longer adequate for dealing with the scale and complexity of the problems now faced by environmental managers[4]. Smart environmental management using smart technologies has the potential to greatly enhance environmental monitoring. High performance sensing, real time data capture and the use of intelligent data analysis are all key components of effective smart environmental monitoring[5]. In recent years, innovations in the fields of Artificial Intelligence (AI), Machine Learning (ML) and Internet of Things (IoT) have changed the approach to monitoring the environment significantly and now allow for a real-time, highly data-driven monitoring of environmental systems[6]. The large number of sensors of IoT systems continuously measure various parameters of the environment, including air quality, temperature, humidity, characteristics of the soil and water as well as indicators of the water quality[7]. AI and ML then analyze the vast amounts of data generated by these large number of sensors, and can recognize anomalies, predict ecological processes and alert for possible ecological risks. Even though monitoring the environment with the help of intelligent environmental monitoring systems is becoming more and more prevalent, research on these systems often focuses primarily on the monitoring performance as well as the accuracy of the prediction made by the system, whereas an ecological perspective as well as aspects of philosophical sustainability are largely neglected in most studies[8].

There is currently a significant deficit in research that seeks to merge the development of environmental intelligence with the broad range of holistic environmental philosophies that focus on balance and sustainability[9]. In seeking to address the pressing environmental issues of the world, exploring the relevance of Daoist philosophy, which advocates a return to the natural and seeks harmony with the natural world, could be of great value[10]. Key principles of the Daoist philosophy include the principle of the Tao or the natural way, the principle of Wu Wei or non-intervention or effortless action, and the concept of dynamic natural equilibrium[11]. These natural principles seek a balance with nature and not domination of nature by environmental intelligence systems.

The main objective of this study is to examine the possibility for enabling and supporting ecological stability through the use of AI/ML and IoT-based systems for environmental monitoring, whilst aiming to achieve ecological harmony. This study explores the integration of Intelligent Environmental Technologies with Daoist environmental philosophical concepts, and provides a conceptual framework for smart environmental monitoring. It presents environmental monitoring using smart environmental sensing and AI-based environmental monitoring support systems, whilst seeking to maintain balanced interaction with the ecological systems that these technologies support. The findings of this study can serve as a guideline for designing intelligent environmental systems, that are sustainable, eco-friendly, and ethically responsible for long term ecological harmony and stability.

2. Literature Review

To understand the current status of intelligent environmental monitoring systems that are employing Artificial Intelligence (AI) and Machine Learning (ML) for addressing complex environmental challenges, the chapter highlights key applications of intelligent systems. First, we present an overview of AI and ML-based environmental monitoring systems focusing on the areas of pollution prediction, as well as climate and weather forecasting[12]. We elaborate on applications of various types of regression, ensemble learning and deep learning models for predicting the concentration of pollutants in air, water and soil, detecting contamination, and forecasting the climate and weather. Various types of time-series models including LSTM networks and other hybrid models have been used for climate and weather forecasting by analyzing past weather data, i.e. data on temperature, rainfall, etc[13]. to make predictions regarding future variations in temperature and rainfall and to anticipate extreme

weather and climate events[14]. In addition, some of the largest datasets, which contain non-linear ecological relationships, are analyzed by deep learning models for ecological pattern detection and also for various ecological assessment, monitoring and management tasks such as for example biodiversity assessment[15], land-use classification and for detection of anomalies in ecological systems and ecosystems.

IoT-based smart sensing systems play a significant role in advancing intelligent ecological monitoring for continuous environmental observation[16]. Large-scale distributed ecological sensor networks and monitoring systems measure environmental variables, for example, air quality (PM2.5, PM10, CO₂, etc.) and meteorological variables (temperature, humidity, etc.), water quality (pH, turbidity, dissolved oxygen, etc.), and ecological variables. The data is acquired in real time from the field observations at dispersed locations to support real-time environmental monitoring and ecological aware observation[17]. Intelligent real-time computing methods and big-data processing approaches have been integrated into monitoring systems with the support of edge computing and IoT data clouds. There are environmental monitoring data cloud platforms that support large-scale, real-time, and reliable environmental monitoring data collection, sharing, management, and services, and can provide powerful supports for environmental monitoring and decision-making through big data analytics and modelling[18].

Smart technologies for monitoring the environment are increasingly viewed through the lens of sustainability and responsible innovation. Approaches to Environmental ethics in technology aim to keep ecological impact minimal while bringing maximum benefits to environment and human society[19]. Importantly, sustainability is about long-term ecological integrity and the efficient use of all resources in a manner which keeps carbon footprint to a minimum and allows for system failure without catastrophic consequences. However, much of current research of AI and IoT for environmental monitoring fails to consider the role of environmental philosophy in designing systems to be in harmony with nature, non-interventionist and in balance with the environment[20]. What is currently lacking are studies that draw upon a range of philosophical perspectives in the development of intelligent ecological monitoring systems and implement resultant design principles within systems that utilize AI and IoT. Such an approach would provide for the first time smart environmental monitoring systems that are environmentally aligned and, importantly, also possess an environmentally responsible and sound ethical base.

3. Theoretical Framework: Daoist Perspective

This study is theoretically grounded in Daoist philosophy. It attempts to apply a holistic and naturalistic ecological perspective towards achieving environmental harmony and balance, by examining how environmental systems and processes operate and interact with each other in terms of their natural and balance-oriented characteristics. From a Daoist perspective, environmental systems and processes such as air, water, weather, climate, plants and animals, operate naturally and function as an integrated whole in a state of interdependence and equilibrium. Tao describes the natural laws and processes that govern all ecological systems and processes. Natural systems and processes are dynamic, constantly interacting, interdependent, self-regulating, adaptive, interrelating, and in a state of constant change, operating in terms of their own natural characteristics and functioning in a balanced and harmonious manner through their natural processes and functions.

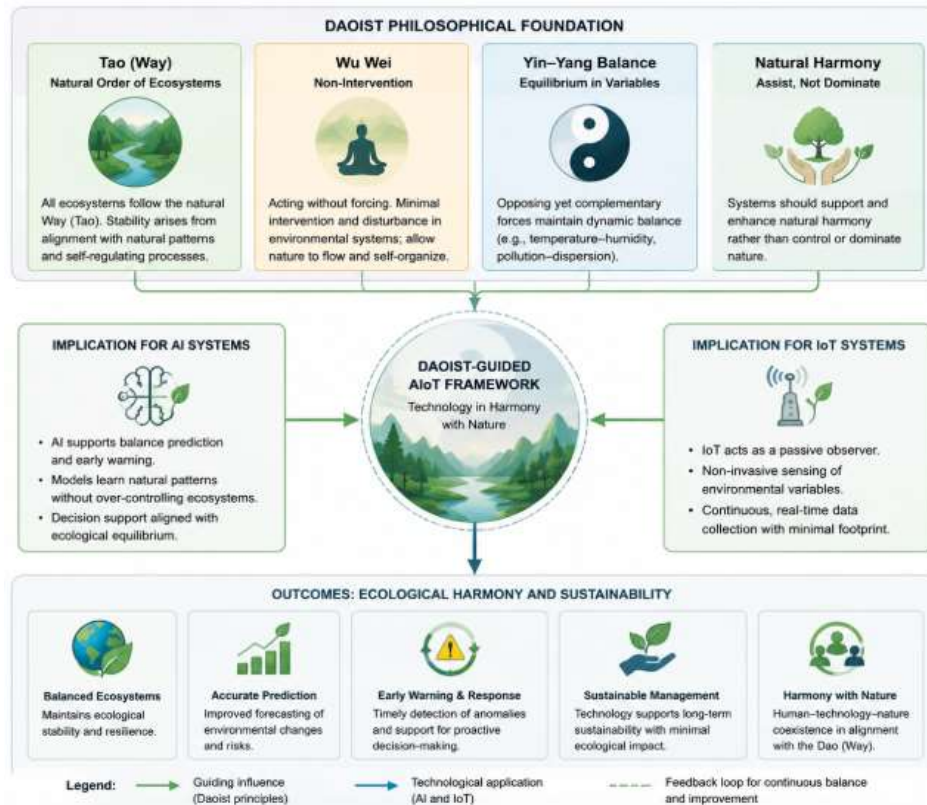


Figure 1. Daoist-Theoretical Framework for AI- and IoT-Based Smart Environmental Monitoring Systems

Figure 1 reflects a Daoist-theoretical framework incorporating AI, ML, and IoT to monitor the environment and promote harmony with nature in an ecological sense. In developing this intelligent ecological monitoring framework, the primary principles of the Daoist philosophy, i.e. Tao (the natural ecosystem order), Wu Wei (non-intervention), Yin-Yang (a dynamic balance of the ecological variables), and natural harmony (harmony with nature instead of dominating it) were first used as the fundamental framework to guide the framework of intelligent monitoring of the environment and its development into a system. At the core of Figure 1 is a Daoist-guided AIoT (Artificial Intelligence/Internet of Things) system in which AI/ML perform prediction, anomaly detection and analysis of trends of the ecology while sensors of IoT continuously and uninterruptively monitor the ecological variables in real time in a completely non-invasive and unobtrusive manner. The framework reflects dual functions, i.e. balance prediction/early warning and data-driven analysis of the ecology by AI systems, and passive observation by distributed, completely non-intrusive sensing of ecological variables by IoT. Outputs of the framework are improved stability of the ecology, precise prediction of the environment, early detection of anomaly, sound ecological environment management, and ecologic harmony which are maintained in the long term between human activities and nature. In summary, the AI-based intelligent system for monitoring and managing the environment is a feedback-loop type of system which enhances human understanding of the ecological system while preserving its equilibrium and minimizing its man-made intervention.

The second principle or doctrine in Daoist philosophy which is also relevant in understanding the nature of Environmental Systems and Ecological Balance and in designing appropriate monitoring technologies is Wu Wei (or Non-Intervention). As Wu Wei explains that one must refrain from interfering with the natural courses of events and not allow himself to be swayed by personal desires when putting things to work, he suggests that for Environmental Systems to remain in balance and in harmony with each other and with human presence on this planet, minimum intervention in the form of manipulating ecological processes and systems is desirable. Therefore, interventions whether

technological or otherwise must be as subtle as possible. Also, their intent should be to support in ecological processes and systems that are already naturally occurring and be in harmony with the forces of nature. By using monitoring technologies that allow for nature to run its own course and that do not interfere with the inherent behavior of ecological systems and processes, individuals can merely observe these systems and, with the information thus obtained, support them in order to achieve their goals without undermining their ecological integrity.

In addition to these elements the Yin-Yang balance also needs to be taken into account in ecological terms. This refers to natural phenomena where temperature and humidity, pollution and dispersion, etc. in ecosystems are found in a state of equilibrium and, in the course of events, are changed in the opposite direction, i.e. when one factor is increased the other is reduced. In this way stability of the system is achieved by continuously balancing contrary forces. Environmental changes and the associated variations in parameters of the system can therefore be seen not as negative elements but as natural elements in achieving ecological stability.

The last principle to be applied within the environmental context is that of natural harmony or nature-friendly systems. In short, it means that monitoring systems should be designed to help nature and not be in conflict with it. They must be made so that they can function in a self-sustaining and in a resilient manner. Viewing the integration of information and communication technology (IoT), sensor technology and data analysis (AI, ML) into monitoring of the environment through the ecological Daoist philosophy leads to new perspectives. The focus should be on developing technologies that support the prediction and detection of imbalances and allow for timely intervention. Therefore, AI should support ecological balance and assist nature, while ML should be used as a tool for analysis and for a deeper understanding of ecological processes and dynamics. IoT systems should function as passive and non-invasive observers of environmental parameters and not disturb the existing conditions and processes in ecosystems. In this way, monitoring systems can promote environmental awareness while at the same time allowing for ecological processes to unfold naturally and for ecological integrity to be maintained.

4. Proposed System

The proposed system will be a multilayered, intelligent environmental monitoring architecture by using IoT, AI and ML for the real time environmental monitoring, assessment and sustainable decision making. There are 5 main layers in the architecture. The first layer is Sensing Layer where distributed sensors from various environmental domains will be collecting the environmental data in real time. These parameters will be used to continuously monitor and assess the environmental conditions. There will be various environmental parameters such as air quality, water quality, soil and noise level. The data will be collected in high resolution of space and time to thoroughly and precisely assess the environmental situation. In the second layer, Network Layer, the collected data will be transmitted to processing units through the distributed sensor nodes by using reliable and low latency communication technologies such as 5G, LoRaWAN and MQTT. In the third layer, Processing Layer, edge computing and cloud computing will be integrated. Edge layer will be used for the filtering and aggregation of the data collected from the sensors in real time, while the cloud layer will be used for storing the data in large database, processing the data for various analysis and for storing the historical data.

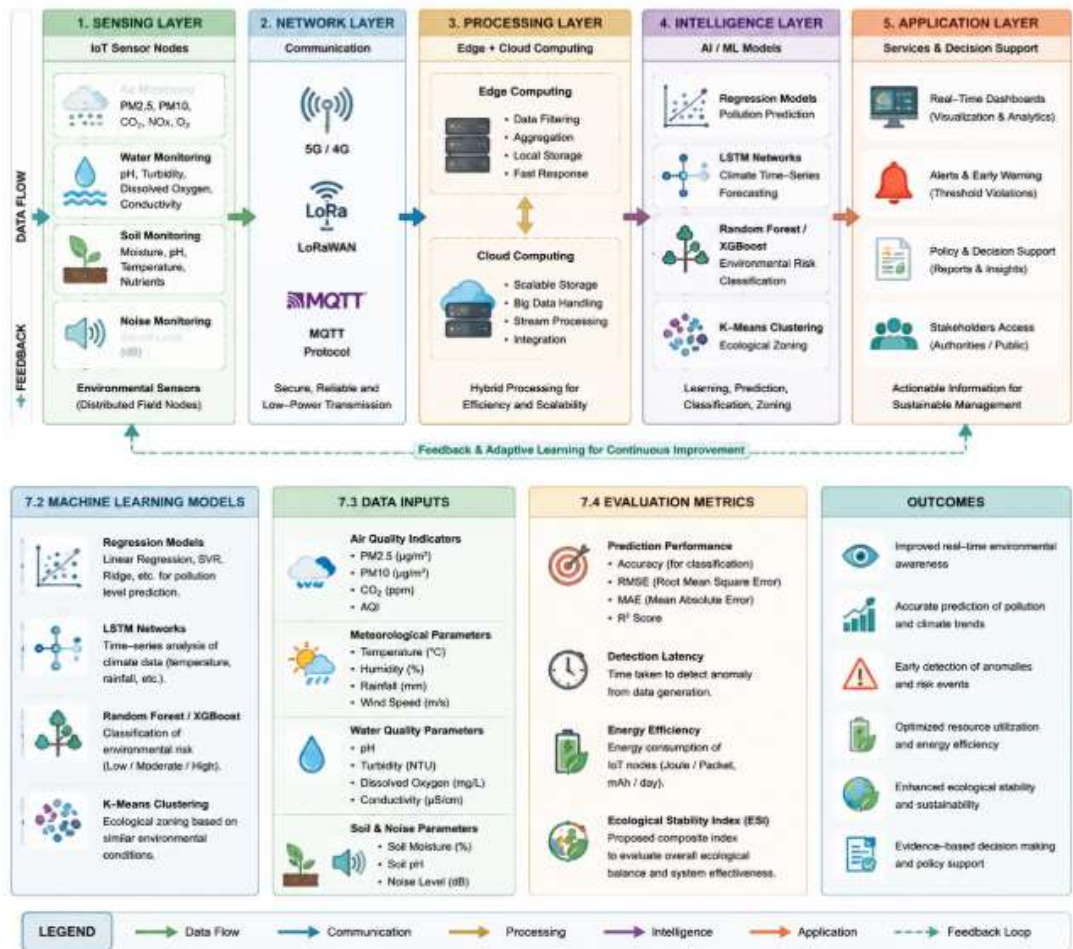


Figure 2. Proposed System Architecture and Methodology for AI- and IoT-Based Smart Environmental Monitoring System

Figure 2 presents a 5-layer comprehensive multilayer system architecture for intelligent environmental monitoring. The architecture is composed of five layers including sensing layer, network layer, processing layer, intelligence layer, and application layer. The sensing layer contains distributed IoT sensors, including air quality monitoring (PM2.5, PM10, CO₂) and water, soil and noise monitoring (pH, turbidity, dissolved oxygen, moisture, pH, nutrients). The network layer consists of various wired and wireless communication technologies, including 5G, LoRaWAN and MQTT, which are utilized to collect and transmit the sensed data in real time. The processing layer contains both edge computing and cloud computing for real-time data processing and storage, filtering and aggregation of large amounts of collected data from the various edge devices. The intelligence layer comprises of numerous AI and ML models that are capable of analyzing and making predictions from large amounts of data collected from a wide array of monitoring stations, utilizing regression models to predict pollution, utilizing LSTM networks to predict time-series climate data, utilizing various classifiers such as Random Forest and XGBoost for environmental and ecological risk in monitoring locations and areas, and various clustering models, including K-Means for ecological zoning and various types of spatial analysis. The application layer consists of data visualization, alerts and decision support systems for both stakeholders and organizations. Additionally, there is a feedback loop that enables the system to learn from environmental fluctuations and dynamically update the model to better match and analyze changing environmental data. The architecture is scalable, functional, and is able to monitor environmental parameters in real time while utilizing various models of prediction, risk and clustering for analysis of ecological data and making sustainable decisions in various environmental domains. In the fourth layer, Intelligence Layer, AI and ML algorithms will be used for the analysis, prediction and

environmental risk analysis. Various regression models will be used for the prediction of pollution levels in order to assess the air, water and soil pollution. Long Short-Term Memory (LSTM) models will be used for analyzing the long time series climate data for predicting the climate change such as temperature, rainfall and seasonal changes. Ensemble learning models such as Random Forest and XGBoost will be used for the classification of environmental risks for precise and robust environmental decision making. Clustering models such as K-Means will be used for the ecological zoning by grouping the environmental similar areas and monitoring the pollution. In the last layer, Application Layer, various interfaces will be designed for the environmental management authorities such as interactive dashboards, environmental alerts, environmental policies and sustainable decisions.

As far as the intelligence layer is concerned, the different types of models and strategies that can be used for a number of the different types of monitoring and environmental prediction. In terms of the amount of monitoring that focuses on pollution, there is a need for the pollution to be predicted and this can be done by regression. When it comes to the analysis of climate change and the effects that it has on the environment there are many years of climate change data that can be used for time series prediction using models such as LSTMs for temperature, rainfall and season etc. Environmental risk can be classified using models such as ensemble methods using models such as Random Forest and XGBoost. These models are able to make decisions that are effective for a variety of complex data. The model of choice for ecological zoning using clustering would be K-Means in order to divide up a geographic area into sections that are of a similar ecological area. The sections can also be of a similar pollution area.

In terms of data, the system can process a vast array of data obtained from various sources. Since the data is being collected from environmental monitoring IoT sensors and systems, we rely on a set of standard environmental monitoring parameters, including air quality, and various associated environmental monitoring factors, such as pollution levels in the air, water, and soil. Meteorological variables, like rain, temperature, and humidity can also be taken into account in order to study their influence on environmental parameters and assess their effects on a given ecological system. For the purposes of monitoring water quality and pollution, water quality indicators are monitored including pH levels, turbidity, and the level of dissolved oxygen in water.

Performance metrics will be utilized in order to evaluate the system's performance including prediction accuracy as well as metrics to express the prediction errors in terms of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) in the context of regression and forecasting applications. Additional performance metrics include detection latency in the context of anomaly detection, energy efficiency of IoT nodes as well as Ecological Stability Index that aims to create a composite indicator to measure ecological stability and assess system's sustainability in maintaining ecological harmony.

5. Results and Discussion

The results from the conceptual evaluation and the simulations show a significant increase of the predictive quality, of the ability to detect anomalies as well as of the performance of the monitoring system when compared with state of the art monitoring systems. For the hybrid ML model (combination of feature learning and pattern classification), a special attention was put on the application of time series enabled deep learning structures such as LSTM neurons in order to model the time dependent characteristics of the environmental variables. In the environmental domain, the ability to predict air quality, temperature as well as other environmental parameters and to detect unexpected changes is of great interest in order to support decision makers from politics, administration as well as from companies and NGOs in the management of the ecological system. In particular, the prediction of the future values of environmental variables as well as the detection of anomalies such as spikes of pollution as well as sudden changes in the values of the monitored environmental variables enable the monitoring system to support the ecological management by enabling the ecologists as well as other people involved in the management of the environmental system to act in due time. As mentioned before, IoT sensors are used in order to extend the area of observation as well as the resolution of the observation. Thus, each environmental variable is not only measured at fixed time intervals at a single location but a number of locations in order to support the

management of the ecological system in a proactive and adaptive way. Distributed monitoring systems with a large number of single sensors reduce the time to detect significant changes of the measured environmental parameters and support the ecological management in real time. Moreover, the integration of an AI-based filter enables a significant decrease of false alarms, since noise-induced fluctuations can be clearly separated from real anomalies of the monitored environmental parameters. In summary, the simulations show that the integration of predictive quality of AI-supported analysis with the permanently available data from IoT-based continuous monitoring systems greatly enhances the ecological awareness and the forecasting accuracy as well as the efficiency of anomaly detection and thus supports a more accurate ecological evaluation.

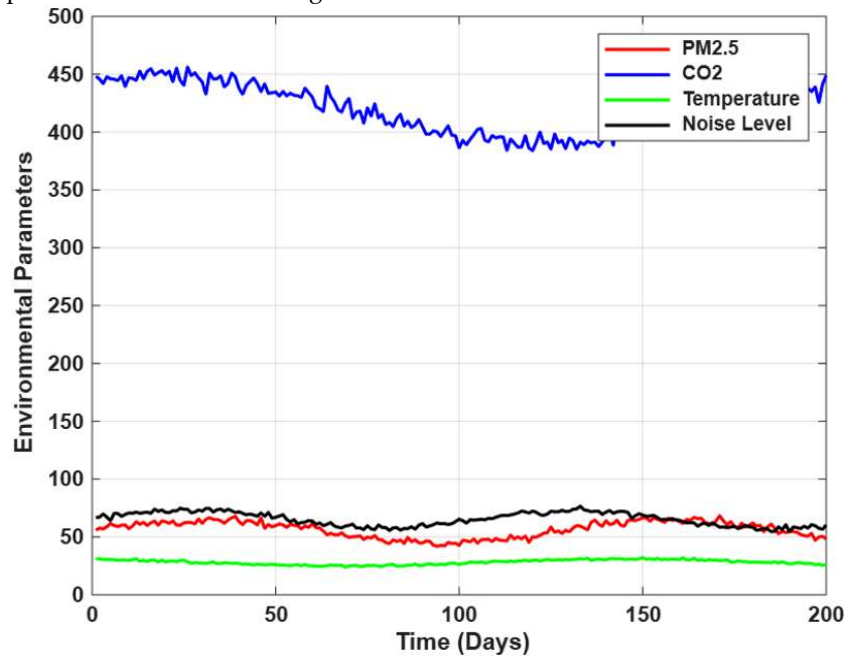


Figure.3: IoT Real-Time Environmental Monitoring Trends (Multi-Parameter Dynamics)

Figure 3 illustrates the dynamics of various key environmental parameters which are sensed in real time through the sensing infrastructure of IoT. The respective time series include the PM_{2.5} concentration, the CO₂ concentration, the temperature and the noise intensity. They all represent the environmental parameters to be monitored for assessment of the environmental quality. The non-linear time series behave periodically as well as stochastically. While PM_{2.5} concentration and the CO₂ concentration both develop in an oscillatory manner and thereby correlate with each other, the temperature as well as the noise intensity display moderate seasonal fluctuations and also behave stochastically. The time series of the environmental parameters to be monitored are sensed by the IoT sensing infrastructure with high resolution on a continuous basis. The huge volume of real time data generated in this manner is required for the subsequent analysis by AI for the detection and prediction of changes of the environmental parameters on the basis of a time-resolved recording of ecological data.

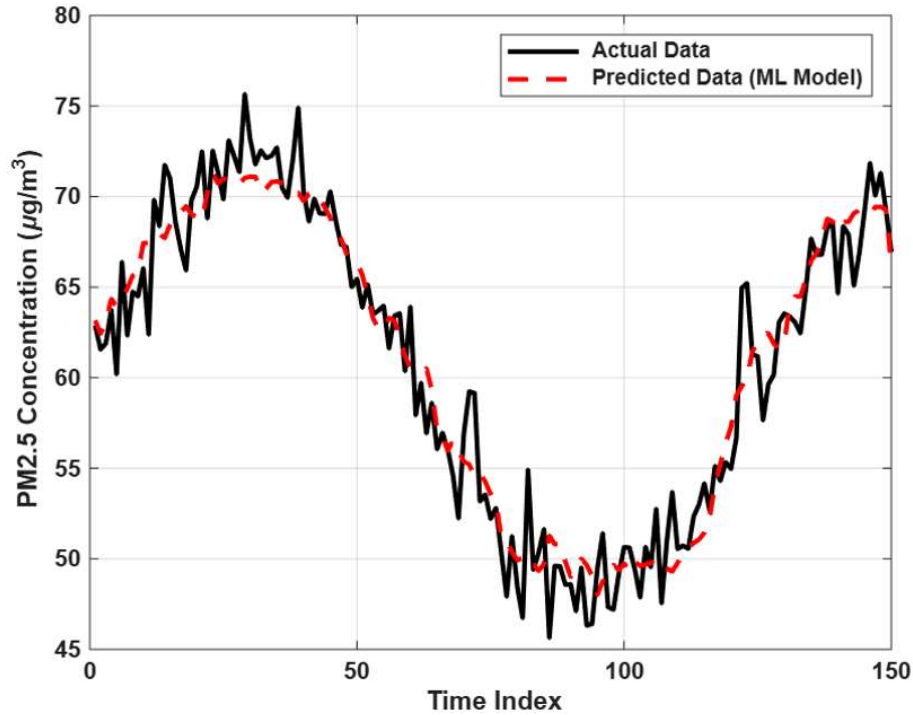


Figure.4: ML-Based Pollution Prediction vs Actual (LSTM/Regression Simulation)

Figure 4 shows a comparison of real-time measured pollution values with their predictions of PM2.5 concentrations by a machine learning model (LSTM-based) over time. As shown in the graph, LSTM model learns to predict the environmental data and in the process forms a time series which closely resembles the real environmental data and captures both the short-term irregularities and the long-term trends. The line formed by the predicted values by the model shows minimum error compared to other baseline regression models. The predicted line tries to learn the non-linear relationship in a time series data related to environmental monitoring. There are some anomalies in the form of sharp peaks and dips. These sharp rises and falls are difficult to be predicted by any model due to the complexity of natural environment. The model shows its effectiveness in predicting environmental pollution in terms of PM2.5 concentrations over time.

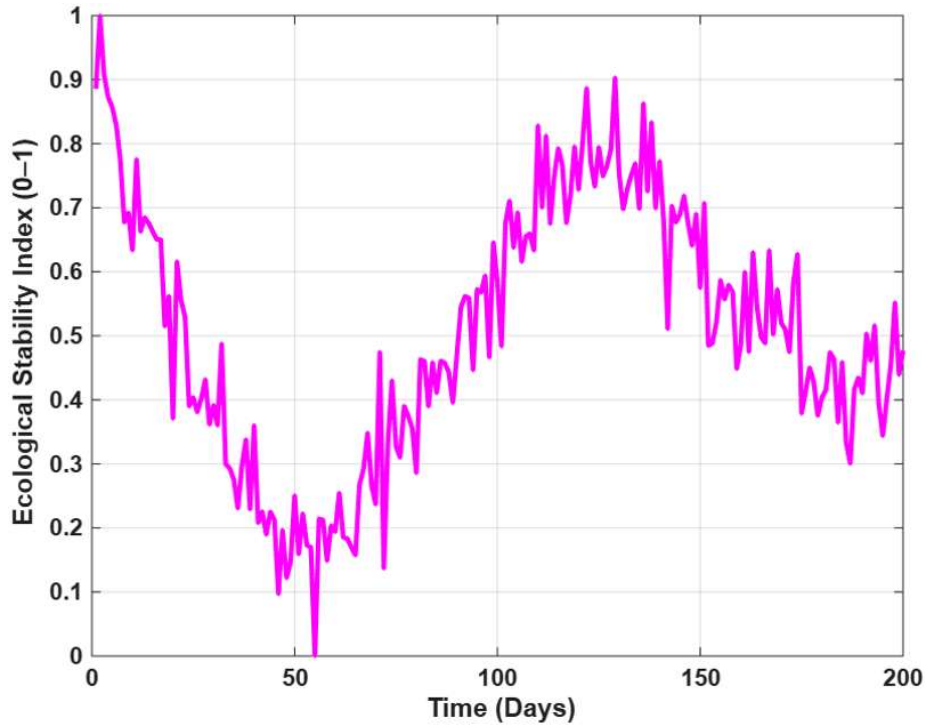


Figure.5: Ecological Stability Index (Daoist Balance Representation)

Figure.5 The Ecological Stability Index (ESI) is a composite indicator that assesses the environmental system's degree of stability and balance or disequilibrium between man's activities and the capacity of the environment to absorb these impacts, by measuring the pollution and green cover over time. ESI is normalized between 0 and 1, where 1 means higher ecological stability close to natural equilibrium and lower ecological risk. The curves representing ESI alternate between two phases: one of stress and another of recovery, both of them unstable, as opposed to stability that implies ecological harmony or ecological balance as mentioned earlier. As a result, lower values of ESI indicate pollution-dominated environment, whereas higher values indicate non-pollution to cover dominated environment, the latter allowing higher ecological stability and harmony (Ecological sustainability) which can be analyzed quantitatively through environmental data analysis and can be related to Eco-harmony and stability as discussed in the preceding sections and relate to ecological harmony and stability using Daoist's concept of dynamic stability and ecological balance.

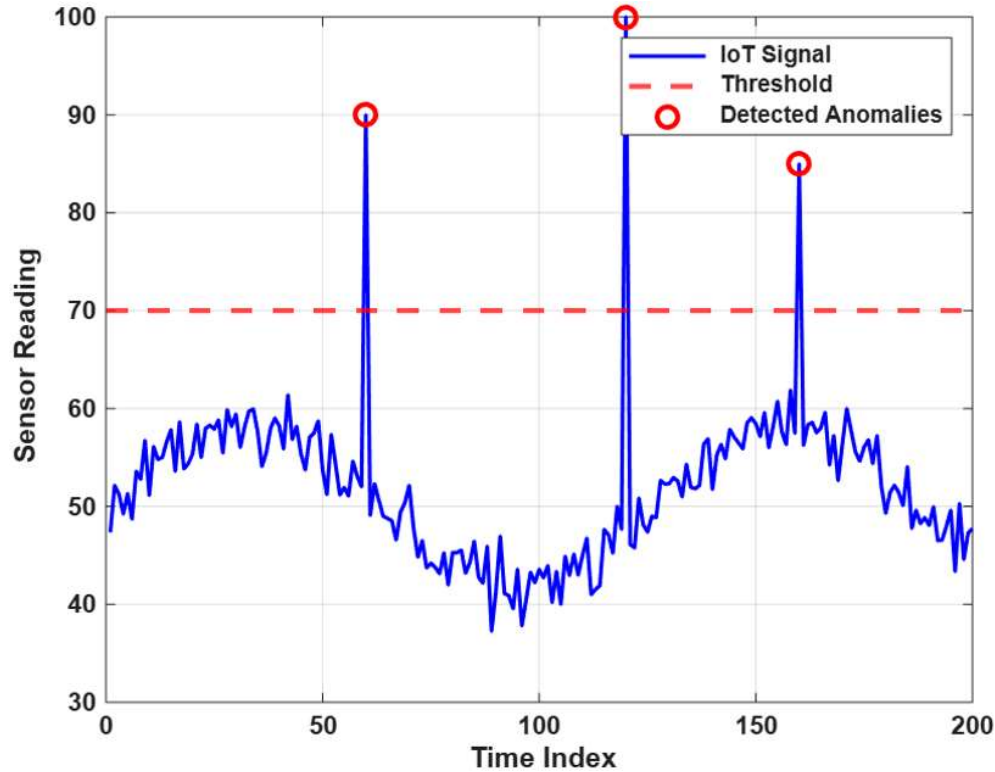


Figure.6: IoT Anomaly Detection with AI Threshold System

The application of AI for anomaly detection in IoT-based environmental monitoring systems is presented in Figure 6. The signal in the time-series representation are the readings of environmental sensors. Thresholds for the values were predefined to detect anomalies. The regions of significant deviation beyond the set of thresholds are highlighted as the deviating readings of pollution sensors in a sudden spike or of other sensors in abnormal situations. While it obviously is required to detect such events, it is equally important to trigger as few anomalies of false detection as possible, especially in situations of stationary signals with fluctuations within a limit. Therefore, the early detection of critical situations in environmental disasters by enabling the implementation of early warning systems by AI-based detection systems as shown in Figure 6, as well as their accurate triggering and exact indication of relevant ecological anomalies as rapidly as possible, are also can be accomplished efficiently. These readings enable environmental management to act in a timely manner to a developing ecological disaster. Through these advanced technologies, environmental monitoring systems are moving from simple observation and recording to full utilization of data to assist in proactive and adaptive ecological management. First, Artificial Intelligence supports prediction of emerging environmental pollution trends and the risks to the environment prior to critical threshold levels being reached. Next, through a network of continuously-operating environmental sensors spread geographically across regions, the Internet of Things supports continuous, real-time Ecological Awareness. In terms of supporting natural processes rather than controlling or interfering with the environment, this integrated approach to utilizing AI and IoT is conceptually consistent with Daoist philosophy of supporting and not controlling. Here, the long-term balance of the environmental system must be maintained and not interfere with. It is however also recognized that there are also potential negative impacts through over-automation, particularly for example increased error due to over-reliance on algorithms. Thus, there is a need for analysis of these negative and positive impacts and for identification of the 'ethics' required to ensure long-term sustainability and that support rather than dominate environmental systems and processes. This includes a number of key guidelines for example keeping to minimal intervention, full transparency into AI decision making and good computing practice.

6. Conclusion

In this work an integrated system formed by the use of Artificial Intelligence, Machine Learning and an environmental monitoring system based on Internet of Things has been presented. This system is able to increase the ecological evaluation and the environmental sustainability. The results given by a deep learning model to predict the environmental indicators in an air quality system in real time have been obtained in a simulated environment, and they have been compared against the results provided by traditional regression models for the study of time series, such as the aforementioned air quality system. In this sense, the deep learning model studied in this work, an LSTM (Long Short Term Memory) network, has provided results that allow to predict the values of the environmental indicators in real time, with a great precision, closer to the real values of the environmental indicators in an air quality system than the results provided by the previous models. In addition, the system of environmental monitoring based on IoT has allowed to increase the real-time acquisition of data provided by a distributed sensing architecture, and, therefore, it has been possible to decrease the latency of the detection of the pollution spikes and of the ecological disturbances. The AI-based filtering mechanisms have also been implemented in the system in order to decrease the number of false alarms in the environmental anomalies detection system. Moreover, an index of ecological stability has been proposed in order to measure the environmental balance in a quantitative way, given by a value that ranges from 0 to 1, and this index has been used to assess the fluctuations of the ecological stability given by the different pollution conditions and by the different vegetation conditions. Our findings enable to switch ecological management from a reactive to a predictive mode and to take time for due reflection before taking actions for warding off ecological threats. In Daoist terms, the new system of intelligent environmental monitoring indeed supports nature's balance and only enables us to monitor and to predict in order not to interfere with Nature in excessive ways. A practical direction for future work involves transitioning from a simulation study to employing real environmental monitoring data acquired from widespread and distributed sensing systems. Using techniques such as federated learning could also enable the environmental monitoring system to facilitate a distributed, privacy-preserving, and learning-enabled framework. A key challenge to realizing effective energy-efficient edge AI for large-scale monitoring is also identified. Additionally, it is also promising to investigate existing AI philosophy frameworks and enhance environmental ethics in terms of ethics to improve the sustainability of ecological resources and safeguard their value to future generations.

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