Internet of Nature (IoN) and Time-Series Analysis for Ecosystem Conservation and Forecasting

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Introduction

Human lifestyles have made significant advancements due to electric technologies. In recent years, the spread of the internet has further enabled individuals to access diverse information easily. The Internet of Things (IoT), which connects devices such as household appliances and cars to the Internet, allowing for remote operation and data collection, has also become commonplace (Madakam et al. 2015).

However, alongside these technological advances, human activities have negatively impacted the natural environment, manifesting in issues such as global warming, ocean pollution, and biodiversity loss. To address pressing environmental challenges, the Internet of Nature (IoN) has emerged as a concept that applies IoT technologies to monitor natural environments and ecological communities (Galle et al., 2019). IoN expands the capabilities of IoT by building integrated networks of sensors, drones, remote cameras, and satellite systems, creating what can be thought of as the “sensory and nervous system” of the environment (Fig.1). Just as the nervous system relays information to maintain homeostasis in living organisms, IoN provides real-time ecosystem data for timely and informed decision-making in environmental management. IoN systems capture fine-scale environmental fluctuations that were previously undetectable through traditional observation methods. By analyzing the data collected from air, water, and soil sensors, IoN platforms can track phenomena such as species migration, vegetation growth, or pollution levels. Time-series analysis and machine learning algorithms process this data, identifying trends and predicting future environmental changes (Zhao et al., 2018). This networked approach to environmental monitoring plays a crucial role in ecosystem and biodiversity conservation, disaster preparedness, pollution monitoring. For example, drone surveillance combined with eDNA analysis allows conservationists to monitor endangered species in remote areas, while satellite-based systems detect forest fires or water-level changes in real time (Kumar et al., 2021). IoN's integration of high-speed communication networks ensures that large datasets can be analyzed on the fly, helping to mitigate environmental risks before they escalate. This makes IoN an indispensable tool for global efforts toward sustainability and climate resilience.

By integrating various environmental observation methods, such as sensing technologies and drones, and analyzing ecosystem data, IoN has the potential to provide real-time monitoring of environmental changes and contribute to sustainable environmental management. Here, we emphasized some examples to discuss the potential availability of IoN to ecological conservation as well as using time-series analysis to forecast future ecosystem dynamics.

IoN's Contribution to Environmental Monitoring

This paper expands on the potential of the Internet of Nature (IoN) technology to revolutionize environmental monitoring by employing drones, sensors, cameras, and remote sensing technologies. These interconnected systems enable the real-time tracking of environmental changes, ensuring more precise and rapid responses to ecological challenges. With machine learning algorithms applied to IoN data streams, time-series analysis can identify patterns in complex ecosystems, predict ecological shifts, and detect environmental anomalies early (Zhou et al., 2019).

Disaster Prediction and Monitoring by IoN

In disaster-prone regions, IoN-enabled networks using UAVs (unmanned aerial vehicles) and satellite-based remote sensing provide continuous monitoring of environmental parameters such as rainfall, river water levels, soil moisture, and vegetation health (Zhao et al., 2018). Multi-spectral cameras and thermal sensors mounted on drones deliver real-time insights during wildfires and floods, guiding emergency responses. Additionally, the integration of IoN platforms with weather data allows the prediction of disasters like floods and landslides through time-series analysis, reducing human and economic losses (CRED, 2021).

IoN for Agricultural Monitoring

IoN plays a critical role in modern agriculture, supporting precision farming techniques by monitoring environmental and crop conditions. IoT sensors embedded in the soil and drones flying over agricultural fields provide high-resolution images that help farmers assess crop stress, soil moisture, and disease outbreaks (Rud et al., 2022). Time-series analysis applied to this data allows for early detection of climate risks and facilitates optimal irrigation and fertilization schedules, improving yield predictions and reducing resource waste. Weather forecasts combined with drone-based observations further assist in planning agricultural activities, increasing farm resilience to unpredictable weather patterns.

Monitoring Urban Ecosystems using IoN

IoN enables continuous tracking of biodiversity and environmental conditions within urban ecosystems. AI-powered cameras and acoustic sensors can monitor bird populations, insect diversity, and vegetation growth in real time, providing insights into urban ecology (Francis & Barber, 2013). For example, urban blackbird populations have been found to sing at higher frequencies in response to urban noise pollution, reflecting adaptation to anthropogenic environments (Nemeth & Brumm, 2009). IoN platforms can process acoustic data collected by microphones placed in cities to track species diversity and assess the health of urban ecosystems. These insights support sustainable urban planning by integrating biodiversity conservation with urban development efforts (Zhou et al., 2019).

Marine Microplastic Monitoring with IoN

IoN offers enhanced solutions for addressing marine plastic pollution. Autonomous drones and underwater robots equipped with AI-based image recognition and sonar sensors allow continuous monitoring of marine ecosystems. These drones can detect microplastic concentrations and marine debris across vast ocean areas, providing geo-referenced data on pollutant sources and movement patterns. Remote sensors can collect data on ocean currents, salinity, and temperature, which IoN platforms analyze to predict where plastic debris will accumulate (Mizuno et al., 2022). This predictive capability helps environmental agencies target clean-up operations more efficiently and monitor long-term recovery efforts.

The integration of drones, cameras, sensors, and satellite data within IoN systems represents a paradigm shift in environmental monitoring. IoN provides continuous, automated tracking of environmental conditions across ecosystems, enabling proactive interventions that mitigate ecological risks. By applying big data technologies and time-series analysis, IoN ensures that the vast amounts of ecological data collected are transformed into actionable insights, advancing efforts toward sustainable management and conservation practices.

Time-Series Data and Environmental Monitoring

Time-series data consist of observations collected at regular intervals, capturing trends, seasonal variations, and random fluctuations (Chatfield, 2004). Sensors, drones, and other IoT devices offer seamless collection of such data across diverse ecosystems. The widespread availability of IoT technology facilitates real-time data acquisition in urban environments, enabling AI and machine learning techniques to identify patterns and trends from complex datasets (Zhao et al., 2018).

Biological and ecological datasets, however, often suffer from challenges such as limited temporal coverage, irregular sampling, and missing values (Molenaar et al., 2022). Advanced analytical tools, including imputation algorithms and machine learning models, are needed to manage these inconsistencies and provide actionable insights for environmental management. IoN systems help integrate fragmented datasets to generate comprehensive forecasts, bridging gaps in traditional data collection methods.

Conclusion and Future Remarks

The integration of IoN technologies and time-series analysis enhances environmental monitoring and forecasting, contributing to the development of a sustainable society. IoN provides solutions to a wide range of environmental challenges, including urban ecosystem conservation, marine pollution mitigation, disaster preparedness, and precision agriculture. By combining sensor technology, remote sensing, and environmental DNA analysis, IoN systems capture high-resolution environmental data that can be processed using big data techniques to predict ecosystem changes with greater precision (Francis and Barber, 2013; Zhou et al., 2019).

The proposed time-series framework facilitates real-time anomaly detection, offering insights into environmental fluctuations not easily captured through traditional methods. These capabilities help policymakers and conservationists respond more effectively to ecosystem disturbances, promoting biodiversity conservation and sustainable management across urban, agricultural, marine, and forest ecosystems.

Future advancements in IoN technology should focus on improving data processing speeds, reducing sensor power consumption, and leveraging the growing reach of 5G networks. High-speed internet will further enhance the transmission and analysis of real-time environmental data, increasing the efficiency of monitoring systems (Rud et al., 2022). Such advancements will accelerate the detection of environmental anomalies, ensuring timely interventions that reduce the impact of natural disasters. Additionally, they will foster greater public interest in environmental issues, encouraging collective actions toward achieving the Sustainable Development Goals (SDGs), thereby supporting the foundations of a sustainable and resilient society.

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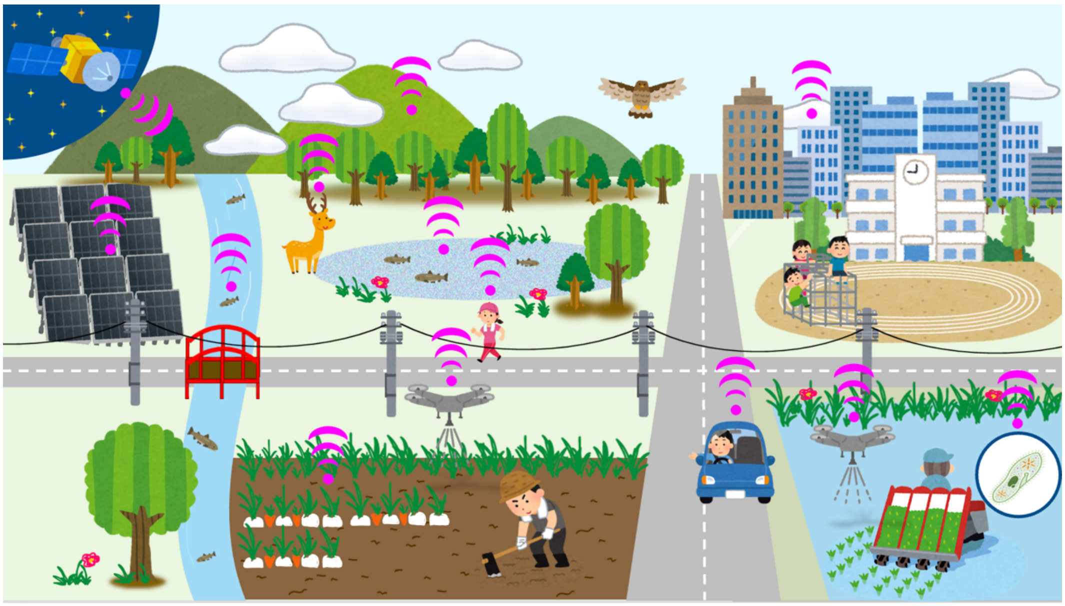

Figure 1 The illustration for the Internet of Nature (IoN) for environments including urban areas, agriculture and natural habitats. The symbols are mainly provided by Irasutoya.com (https://www.irasutoya.com).