Review Paper:

A Review on Application of Innovative Techniques for Sustainable Environmental Management in Mines

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Abstract

This study focuses on the application of innovative techniques for sustainable environmental management in mines. It highlights the importance of minerals as finite and non-renewable natural resources and the role of the mining sector in catering to global energy and industrial needs. It also describes the challenges of waste generation in mining and the need for responsible extraction practices to contribute to national and community development. It emphasizes the significance of the mining industry in India as a core part of the economy.

The study delves into waste dump management, exploring the use of coir mats and grass seeds for aesthetic and sustainable plant growth. The adoption of Internet of Things (IoT) technology is proposed for real-time monitoring and management of vegetation in mining areas which includes the use of sensor technology, cloud computing and advanced analytics for ecological monitoring, particularly in forest environments. The study also addresses the need for real-time technology to enhance vegetation, to protect wildlife and to improve the livelihoods of tribal communities.

Keywords: Waste dump management, Environmental parameter monitoring, Internet of Things, Internet of Trees.

Introduction

Minerals, as finite and non-renewable natural resources, are crucial for various industrial activities and energy production worldwide. The mining sector plays an important role in fulfilling the growing demand for minerals and metals, which is essential not only for country's economic growth but also for improving the living standards of its population. However, the industry faces the challenges of integrating environmental, social and sustainability considerations into its operations to ensure responsible and holistic mineral and metal extraction, contributing to both national and community developments. In India, the mining industry is a key part of the economy, providing essential raw materials to numerous vital industries. Mining processes including extraction, beneficiation and processing, generate substantial waste.

The first stage excavation involves removing ore from the earth, typically through drilling and blasting. This results in a large volume of waste, such as soil and debris, often stored in stockyards within or near the mine area. The scale of the mines directly impacts the amount of waste produced, with opencast mines being more polluting due to their higher waste generation compared to underground mines. In fact, open-pit mines can produce up to ten times more waste than underground mines. Processing the extracted ore to recover minerals also creates significant waste, as only a small portion of the ore contains recoverable metal. With higher-grade mineral deposits becoming scarcer, the industry increasingly relies on lower-grade reserves, leading to even more waste production[1].

The advent of the Internet of Things (IoT) has revolutionized waste management in the mining industry, enhancing safety against fires in dump areas. IoT technologies such as sensors, automation, self-driving vehicles and real-time data analytics, have significantly improved worker safety, productivity and efficiency in the mining sector, transforming traditional practices[3].

Waste Dump Management

The management of waste dumps is a critical concern in the mining industry. Covering these dumps with coir mats and seeding them with grass not only enhances their appearance but also fosters sustainable plant growth through natural seed dispersal. The use of Internet of Things (IoT) technology can monitor the health of vegetation on these dumps, detect disturbances or movements in the slopes and provide early warning of potential fires. Initially, these dump slopes are often colonized by grass species such as stylo, lemon grass, vetiver and millets, which have a short life cycle and tend to dry out, especially in the absence of water during dry seasons. The accompanying image (Figure 1) illustrates the successful stabilization of a dump at the Magnesite Mines in Karya, Mysore district.

The concept of "Digitalization of the dump area" involves integrating advanced technologies into the management of dump vegetation and climax forests. This approach enhances monitoring, data collection and analysis in research and development focused on forest environments. Key technologies for achieving these goals include IoT, Wireless Sensor Networks, the Internet of Trees and Deep Learning. Intelligent systems are increasingly used for sensing and monitoring environmental factors like forest fires, drying of slope beds, soil moisture levels and temperature changes around dump areas. IoT applications are particularly valuable for analyzing flora, predicting forest fires and other related tasks[7].

Forest fires, a significant factor in deforestation, destroy hundreds of trees annually worldwide. These fires, often exacerbated by hotter summers and warmer winters, result in substantial loss of forest cover regardless of whether they are human-caused or accidental. From 2003 to 2017, India recorded 520,861 active forest fire incidents, predominantly in the dense forests of the eastern and lower Himalayas. These fires not only contribute to biodiversity loss but also negatively impact the productivity and carbon storage of terrestrial habitats. They lead to soil fertility decline, affecting crop yields and increasing atmospheric pollution. Forest fires also heighten the risk of landslides and contribute to climate change by raising global warming and greenhouse gas emissions. Additionally, they cause soil erosion, flooding, wildlife extinction, habitat loss, food insecurity and overall biodiversity loss.

Overview of IoT and Its Applications

IoT refers to the linking of physical objects with a digital environment via Internet Protocol (IP) connectivity. This interconnection offers unique capabilities that significantly improve upon traditional applications. GSMA Intelligence predicts a significant increase in IoT connections, projecting that they will surpass 25 billion worldwide by 2025.

IoT represents a revolutionary, real-time technology that can significantly impact the mining industry by introducing smart capabilities and real-time monitoring to address various issues. It enables continuous monitoring of dump vegetation and the surrounding environment, tracking potential fire incidents, assessing crop health, evaluating vegetation continuously and monitoring plantation growth and logging activities. Advances in wireless communication and sensor technology have made IoT an affordable and innovative approach for mapping vegetation and collecting information about plantations in dump areas[5].

The wireless communication protocol allows for the transmission of sensory data from the slope to a cloud server, enabling real-time monitoring and analysis. This server can store and visually represent data on a Graphical User Interface (GUI). Artificial intelligence and big data analytics can be applied to this sensory data to determine the causes and effects of environmental variations on the dump slope. In this digital age, there is a focus on utilizing IoT to digitalize the status of forest vegetation, dump slope vegetation, or afforestation. This technology not only offers distinct IoT-based cloud platforms for data storage and analytics but also supports the Internet of Trees for real-time monitoring of environmental parameters, detection of illegal logging and identification of forest fires. Moreover, it facilitates the integration of internet-based modules for the advanced wireless tracking and monitoring of wildlife.

Digitalization in forests is characterized by its ability to provide instantaneous data, monitoring and inventory of the forest environment. The key features of this digital transformation include:

a) **Sensing Technology:** This technology establishes a connection between the physical and virtual worlds. Sensors not only capture signals but also convert them into digital data for further processing. They accurately relay information about the physical environment, turning it into useful knowledge.

Fig. 1: Dump Stabilization at Magnesite Mines, Karya, Mysore District

b) Human-Forest Interaction: Human involvement remains crucial in the digitized forest setting. The integration of cyber-physical systems (CPS) within forests is significant. Displaying CPS data on portable devices helps humans in decision-making, highlighting the need for robust communication technologies and user-friendly, touchscreen-based handheld devices.

c) Big Data and Cloud Computing: The interaction between humans and embedded forest systems generates substantial data that needs storage. Cloud computing offers a digital platform for data storage and visualization. It provides cost-effective and intelligent big data analysis, often through pay-per-use models.

d) Advanced Analytics: These sophisticated computational techniques enable the interpretation of data that was previously too complex or time-consuming to analyze. Advanced analytics is crucial for converting large volumes of data into actionable insights for improved decision-making.

e) Artificial Intelligence: AI aims to enable technological systems to learn from observations and experiences, make autonomous decisions and act upon them. This technology is pivotal in advancing the capabilities of digitalized forest systems.

f) Internet of Trees: The concept of the Internet of Trees refers to trees equipped with internet-enabled modules capable of sensing, communicating and monitoring environmental conditions within forests through internet connectivity. This includes real-time monitoring of environmental factors, detection of forest fires and identification of illegal logging activities. Similar to the broader term 'Internet of Things' (IoT), where objects are monitored, communicated with and tracked using Internet Protocol (IP), the Internet of Trees focuses on the forest environment [2,6].

Previous research in this field has primarily concentrated on detecting and monitoring forest fires. Some studies have also examined environmental parameters such as temperature, wind speed, relative humidity and carbon dioxide (CO_2) levels. A notable example is the 2019 Amazon Forest fires, known as the 'lungs of the planet' for their significant oxygen production and CO_2 absorption. These fires, largely attributed to irresponsible human activities, were studied by the Copernicus Climate Change Service (C3S). Their research indicated that the fires in the Amazon not only released carbon monoxide (CO) but also increased CO_2 levels in the atmosphere, posing serious health risks to humans.

Environmental Parameter Monitoring

In various trees within a forest, sensor nodes are installed to monitor environmental conditions in real-time. These sensor nodes typically consist of environmental sensors paired with a wireless communication module. Given that wireless connectivity in forest environments poses a challenge, the implementation of a Wireless Personal Area Network (WPAN) is integrated into the system to address this issue. The WPAN, specifically using the IEEE 802.15.4 Zigbee module, serves as the wireless communication medium in the sensor nodes, facilitating the transmission of environmental data from the forest. This data is communicated by Zigbee to a gateway node, which, equipped with internet connectivity, can then upload the data to a cloud server over Internet Protocol (IP), forming part of the general system architecture as shown in figure 2.

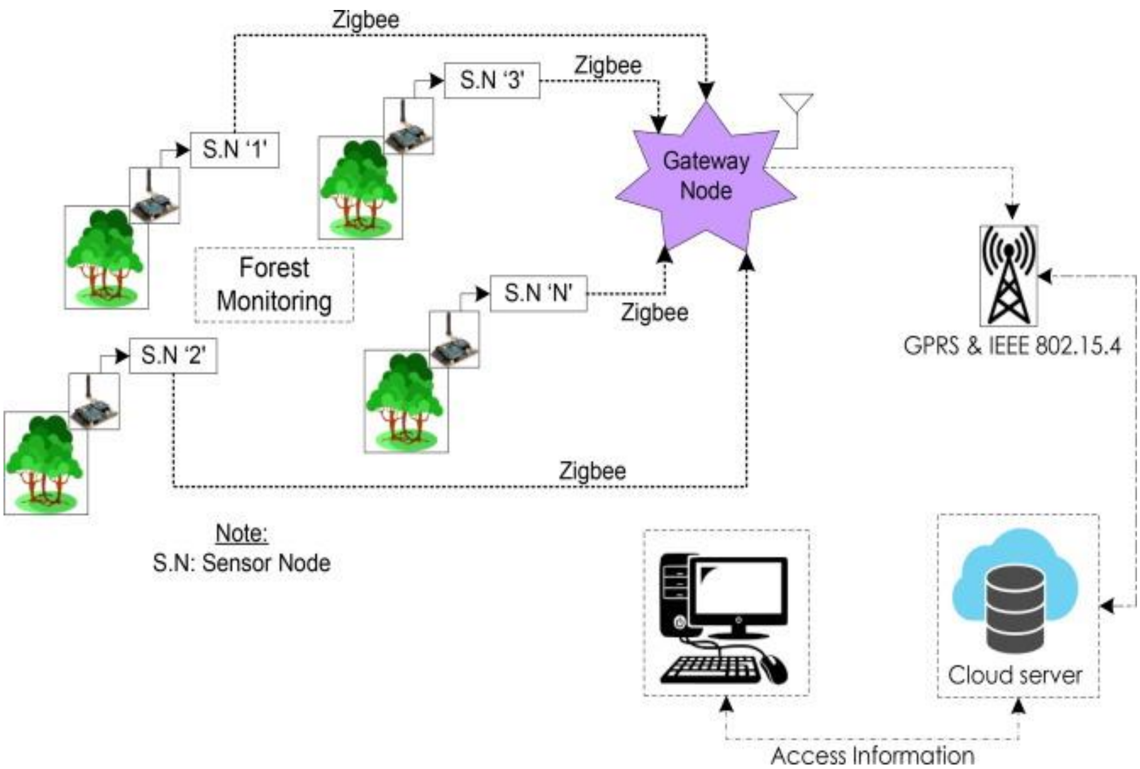

Fig. 2: Architecture of Internet of Trees

Fire Tracking and Monitoring: To identify potential wildfire incidents, Geographic Information System (GIS) and Remote sensing technologies are utilized to map fire-prone areas spatially. While GIS and remote sensing provide spatial data for forest monitoring, there is a need for cost-effective technology to sense real-time environmental parameters in forests. A low-power sensor system, using 433 MHz communication protocol and IEEE 802.15.4, has been deployed for ecological monitoring[8]. Additionally, a Wi-Fi-enabled sensor network has been established for fire detection and monitoring. For detecting wildfires and monitoring environmental conditions, a cloud/fog computing-based solution enabled by Zigbee and IEEE 802.15.4 communication has been proposed[9]. This system integrates an STM32 controller, a Zigbee module and GPRS (Global Packet for Radio Service) to detect fires and communicate information to remote servers. An IoT-based wireless acoustic detection system is also suggested for identifying wildfires, focusing on variations in crown and surface fires.

Aside from fire monitoring, IoT technology has been applied to detect and control illegal logging, a significant factor in forest degradation. An IoT-based surveillance system is proposed to combat smuggling and fire incidents, transmitting information to forest authorities via wireless communication protocols as shown in figure 3. Internet-based modules in this system enhance real-time monitoring of forest events, accessible from anywhere with internet connectivity[4].

However, the existing systems have limitations regarding connectivity, fire detection at edge devices and power consumption issues in sensor nodes. To address these, a new architecture utilizing LoRa communication and an edge computing-based gateway is proposed. This edge gateway, equipped with analytics, is designed to estimate short-term forest fire risks and detect early fire incidents. It incorporates various sensors like temperature/humidity, light intensity, rain, IR and wind speed sensors, enhancing the sensor node's capabilities for a more comprehensive environmental assessment.

The sensor node will operate on battery power and will include local storage for data backup. It will communicate with other gateways using long-range RF. Data from its array of sensors will be processed by a computing unit using onboard algorithms to transform real-time inputs into meaningful information. Additionally, a Computer Vision Node (CV) will be situated near the sensor node to validate, augment, or refine the data gathered by the sensors. This vision-based node will employ machine learning algorithms to analyze environmental images, extracting relevant data from the visual information.

i) Forest Fire Detection and Prediction: The sensor node is designed to detect the onset of a fire through sudden changes in IR, Lux, temperature and humidity readings. Upon detecting a fire, it activates a central analysis node's fire status prediction system. This system will assess various factors such as wind speed, temperature variations across different sensor nodes (indicating fire direction) and data from the CV node regarding local vegetation types. The central analysis node will then deduce fire characteristics like intensity, direction and spread rate. This information is vital for forest department or mining offices to strategize effective fire containment or prevention methods.

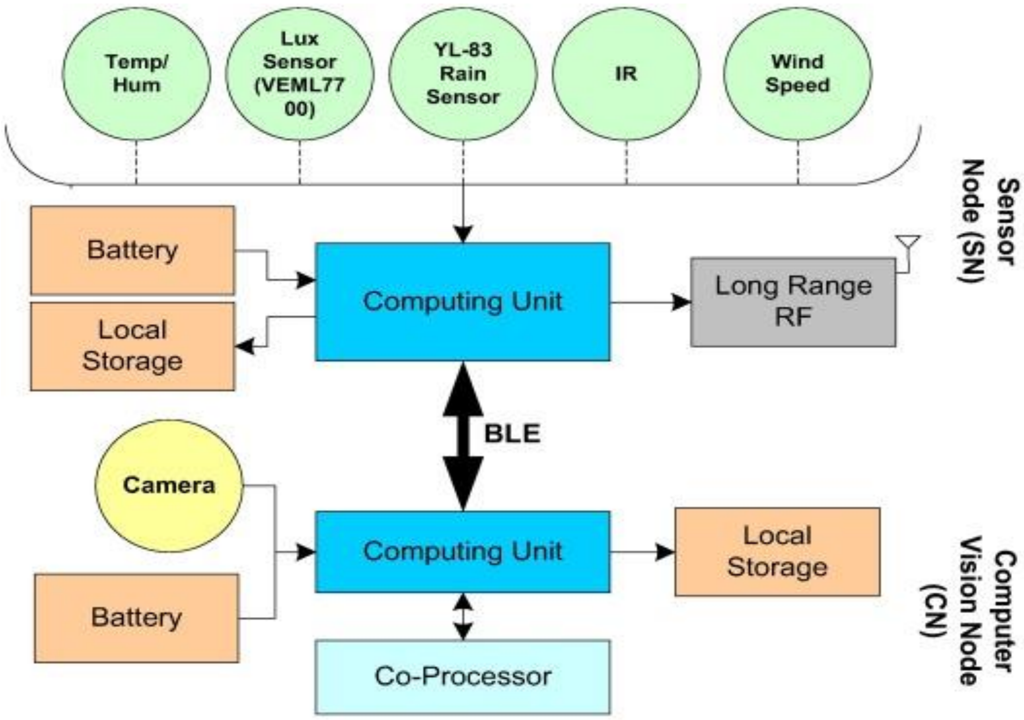

Fig. 3: Architecture of IoT-based Surveillance System

ii) Flora Analysis: The sensor node will correlate environmental parameters like temperature, humidity, lux and wind speed with data from the CV node. This comprehensive data set provides insights into the growth conditions of local flora, assisting botanists in researching and developing genetically suitable plant strains for different environments.

iii) Raw Data Acquisition: The sensor and computer vision nodes process environmental data and relay it to the central analysis node. This design allows further analysis to be conducted centrally, without modifying the forest-based systems. This architecture enables more efficient research and development using the collected raw data, reducing time and effort needed for environmental data collection and fostering future research.

iv) Real-Time Sensing: Real-time sensing technologies are crucial for forest authorities to monitor activities like poaching, illegal logging, fire incidents and changes in forest cover. Although currently limited in implementation, expanding real-time sensing in forest monitoring can greatly aid in predicting changes in vegetation and forest coverage.

v) Energy Harvesting of Sensor Nodes: Typically, sensor nodes rely on batteries, necessitating regular checks by mining authorities. Solar energy harvesting presents a solution to this energy challenge, serving both as a primary power source and a backup to prevent data loss and connection interruptions.

Conclusion

Mining dump vegetation and climax forests are crucial for maintaining environmental equilibrium. The deterioration of these forests significantly increases greenhouse gas emissions, adversely impacting all life on Earth. Forest degradation, often caused by fire incidents and tree logging, also has a profound effect on wildlife. As these natural habitats are integral to the well-being of wildlife and the livelihoods of tribal communities, there is a pressing need for real-time technologies capable of monitoring forest conditions.

The Internet of Things (IoT) offers a viable solution for this. By integrating IoT modules into forest ecosystems, real-time monitoring can be achieved, supporting environmental sustainability and maintaining ecological balance.

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(Received 21st November 2024, accepted 25th December 2024)