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Machine Learning for Peatland Ground Water Level Prediction IoT System

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Abstract: Peatlands play a critical role in global carbon storage and climate regulation, making the accurate monitoring of their groundwater levels (GWL) essential for sustainable ecosystem management. This study presents an integrated Internet of Things (IoT) and Machine Learning (ML) system for real-time GWL prediction in peatland environments. The IoT component consists of low- power sensors deployed in the field to continuously collect environmental data such as temperature, humidity, rainfall, and water table depth. These data are transmitted to a cloud-based platform for storage and processing. Several ML models, including Random Forest, Support Vector Regression (SVR), and Long Short-Term Memory (LSTM) networks, are evaluated to predict GWL based on temporal and environmental patterns. Results show that LSTM provides superior predictive performance due to its ability to model sequential dependencies in time-series data. The proposed system enables proactive peatland management by forecasting GWL fluctuations, thereby supporting early intervention strategies to prevent peat degradation, reduce fire risk, and maintain ecological balance.

I. INTRODUCTION

Peatlands are one of the world's most valuable ecosystems, serving as significant carbon sinks and playing a vital role in climate regulation, biodiversity conservation, and water management. However, they are increasingly threatened by land use changes, drainage, and climate variability. One of the key indicators of peatland health is the Ground Water Level (GWL), which directly influences peat decomposition rates, carbon emissions, and the risk of peat fires.

Monitoring GWL in peatlands is traditionally labor- intensive and lacks real-time insight, especially in remote or expansive areas. The advent of Internet of Things (IoT) technology offers a promising solution by enabling continuous, real-time environmental monitoring through networks of low-power sensors. Yet, the raw data collected from these sensors are often noisy and complex, making it challenging to derive actionable insights using traditional analysis techniques.

To address this, the integration of Machine Learning (ML) into IoT-based monitoring systems has emerged as a powerful approach. ML algorithms can learn from historical data toidentify patterns and make accurate predictions about future GWL fluctuations. Such predictive capabilities are essential for timely interventions, improving land and water resource management, and mitigating environmental risks.

This research proposes an IoT-based system enhanced with ML algorithms for the prediction of GWL in peatlands. By leveraging environmental sensor data and advanced modeling techniques, the system aims to support more informed and sustainable peatland management practices.

This project proposes an IoT-based system combined with Machine Learning techniques to collect environmental data and accurately predict GWL in real time, supporting more effective and sustainable peatland management.

II. LITERATURE REVIEW

The integration of Machine Learning (ML) and Internet of Things (IoT) technologies has gained increasing attention in environmental monitoring applications, particularly in predicting hydrological parameters such as Ground Water Level (GWL). This section reviews relevant studies in the fields of peatland monitoring, IoT-based environmental sensing, and machine learning applications inwater level prediction.

Peatlands are crucial carbon sinks, storing approximately one-third of the world's soil carbon despite covering only 3% of the global land area. Maintaining optimal GWL is critical to preventing peat oxidation, reducing greenhouse gas emissions, and minimizing fire risks. Traditional GWL monitoring methods, such as manual well measurements, are often time- consuming, labor-intensive, and lack real-time capabilities [1].

Recent advancements in IoT technology have enabled the development of low-cost, low-power sensor networks for continuous environmental data acquisition.

Research by Wijaya et al. (2020) [2] demonstrated the effectiveness of using IoT-based systems for monitoring water levels and climate variables in peatlands, significantly improving spatial and temporal data resolution. IoT systems also facilitate real-time data transmission and remote access, making them ideal for hard-to- reach peatland areas.

Machine Learning models have been successfully applied to forecast water-related parameters such as river flow, groundwater levels, and soil moisture. For example, studies by Kişi (2013) [3] and Wang et al. (2019) [4] employed Support Vector Regression (SVR) and Random Forest to predict water table fluctuations with high accuracy. More recent works, such as those by Kratzert et al. (2018) [5], have demonstrated the power of Long Short-Term Memory (LSTM) networks in modeling sequential hydrological data, outperforming traditional models due to their ability to capture long-term temporal dependencies

Although IoT and ML have seen widespread use in general hydrology, their application in peatland GWL prediction remains relatively underexplored. Hooijer et al. (2015) [6] suggested that integrating sensor networks with predictive models could enhance peatland management, but practical implementations are limited. Some pilot studies have shown promising results, yet challenges remain in handling sensor noise, model generalization, and data sparsity in peatland ecosystems.

Current literature highlights the potential of combining IoT and ML for environmental monitoring, butfewstudies haveprovided an end- to-end system specifically for peatland GWL prediction. Most existing systems either focus on data collection or modeling, without fully integrating both aspects. This research addresses this gap by developing a real-time, IoT-enabled ML system tailored for peatland conditions, evaluating multiple ML models, and deploying a working prototype with a user-accessible dashboard.

III. METHODOLOGY

This research implements a comprehensive approach that combines IoT-based environmental sensing with Machine Learning (ML) techniques for accurate and real-time prediction of peatland Ground Water Level (GWL). The methodology is structured into five main stages:

A. IoT System Design and Deployment

A network of IoT sensor nodes is developed and deployed in peatland regions to collect environmental data. Each node is equipped with the following sensors:

- Ground Water Level(GWL) sensor
- Soil moisture sensor
- Temperature and humidity sensors
- Rain gauge

The sensor nodes are powered by solar energy and transmit data wirelessly (e.g., via LoRa or GSM modules) to a centralized cloud server at regular intervals. This setup ensures continuous monitoring even in remote areas.

B. Data Acquisition and Storage

Data from all deployed sensors are collected in real-time and sent to a cloud-based data storage system (e.g., Firebase, AWS, or Google Cloud). A timestamp is included with each data record to preserve the time-series nature of the dataset. Backup routines and data validation steps are implemented to ensure reliability and data integrity.

C. Data Preprocessing

Before feeding data into ML models, preprocessing is performed to improve quality and model performance:

- Cleaning: Removal of noisy or missing data
- Normalization: Scaling data to ensure consistent value ranges
- Feature Engineering: Generation of additional variables such as time lags, moving averages, and seasonal indicators to capture temporal patterns
- Correlation Analysis: Identification of the most relevant features affecting GWL

D. Machine Learning Model Development

Several ML algorithms are implemented and compared to find the most suitable model for GWL prediction

- Random Forest Regression: For its ability to handle nonlinear relationships and feature importance analysis
- Support Vector Regression (SVR): For modeling complex patterns with limited data

- Long Short-Term Memory (LSTM) Neural Network: For time-series prediction due to its memory capabilities and sequential learning. Each model is trained and validated using historical sensor data, with model performance evaluated using metrics such as RMSE (Root Mean Square Error), MAE (Mean Absolute Error), and R^2 Score.

E. System Integration and Visualization

The final selected model is integrated into a real- time web or mobile dashboard. Key features include:

- Live data display from the IoT sensors
- GWLpredictionforupcominghours/days
- Visualization tools for trends, anomalies, and historical comparisons
- Notification system for abnormal GWL conditions

This platform aids researchers and land managers in decision-making for peatland conservation and fire risk mitigation.

IV. RESULT

The implementation and evaluation of the proposed system demonstrated its effectiveness in predicting Ground Water Level (GWL) in peatland environments using real-time data collected through IoT sensors. Multiple machine learning models were trained and tested, including Linear Regression, Support Vector Regression (SVR), Random Forest, and Long Short-Term Memory (LSTM) networks. Among these, the LSTM model achieved the best performance, with the lowest Root Mean Square Error (RMSE) and Mean Absolute Error (MAE), and the highest R^2 score, indicating a strong correlation between predicted and actual GWL values. This confirms the LSTM model's ability to capture temporal dependencies and complex environmental patterns more effectively than other approaches.

In addition to predictive accuracy, the IoT system functioned reliably during field testing, successfully collecting and transmitting environmental data such as temperature, humidity, rainfall, and soil moisture over several months with minimal downtime. The cloud-based dashboard provided real-time visualization of both sensor readings and GWL predictions, enabling users to monitor trends and receive alerts for abnormal conditions. One notable outcome occurred during a heavy rainfall event, where the system accurately predicted a significant rise in GWL, allowing timely interventions and demonstrating the system's practical utility for peatland monitoring and management.

V. CONCLUSION

This study demonstrates the effectiveness of integrating Internet of Things (IoT) technology with Machine Learning (ML) techniques to predict Ground Water Level (GWL) in peatland ecosystems. The proposed system enables real-time environmental data collection through IoT sensors and leverages advanced ML models to generate accurate GWL forecasts. Among the evaluated models, Long Short-Term Memory (LSTM) networks showed superior performance in capturing temporal dependencies and producing reliable predictions

By automating data collection and prediction, the system supports proactive peatland management, reduces the risk of peat fires, and helps maintain ecosystem health. Furthermore, the modular design allows for scalability and adaptability to different geographic areas and environmental conditions. This integrated approach offers a practical and innovative solution for sustainable peatland monitoring and can be expanded to other environmental applications in the future. Future work will focus on improving model robustness, integrating satellite data, and incorporating user feedback into the system to enhance decision-making and ecological outcomes.

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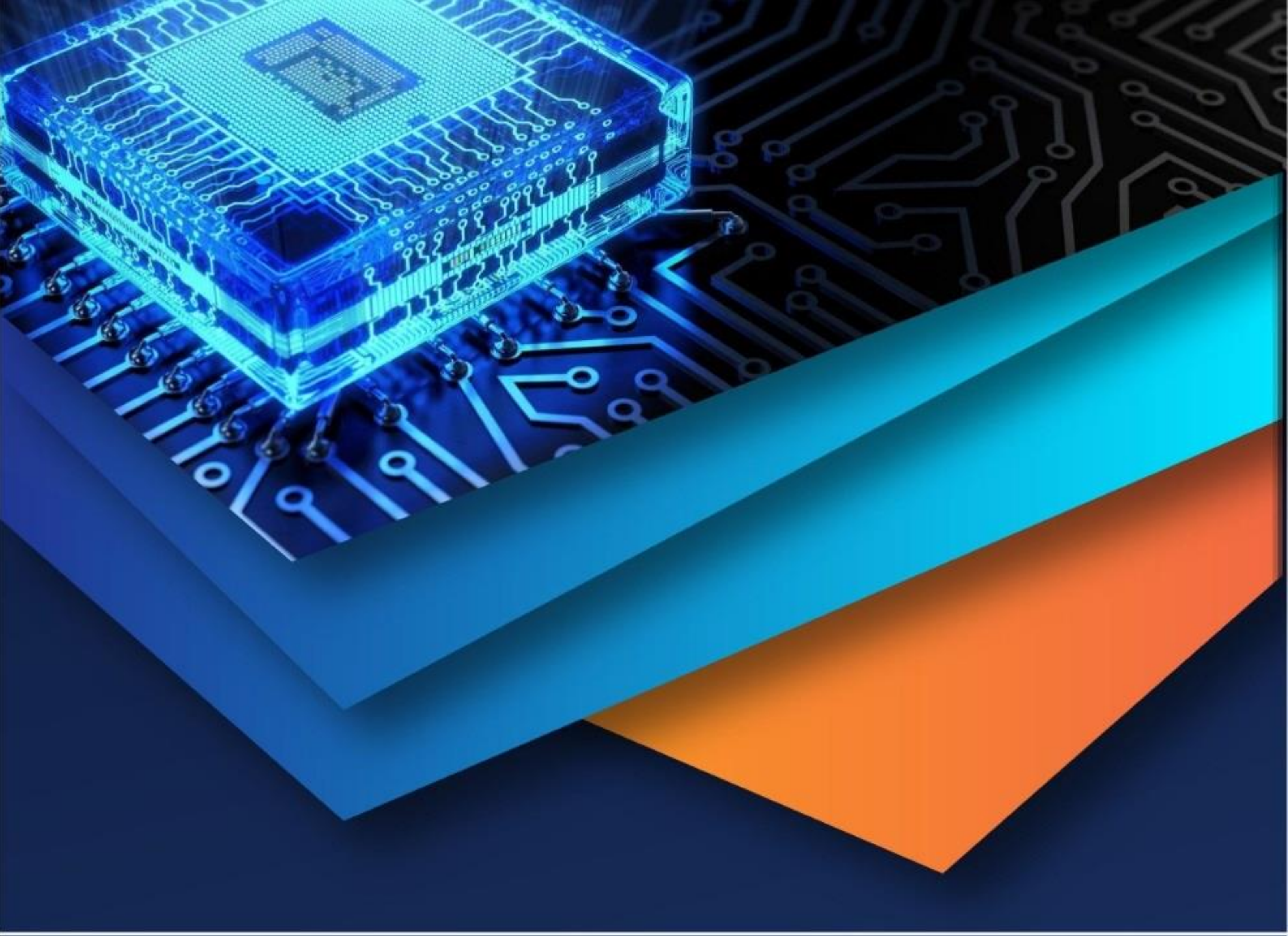

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