Predicting Soil Moisture Levels with Gated Recurrent Units: A Deep Learning Approach Integrated with Internet of Things Data

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***Abstract*--- This study examines the prediction of soil moisture levels using Gated Recurrent Units (GRU) integrated with Internet of Things (IoT) technology. Recognizing the critical role of soil moisture in plant growth and ecosystem health, the research employs real-time data collected from IoT devices, including soil moisture, temperature, and humidity, to enhance irrigation efficiency in agricultural practices. Various prediction samples (n_samples) were analyzed, specifically focusing on n_samples of 6, 12, 18, and 24. The findings reveal that the GRU model with a prediction sample of n_samples =12 achieved the highest accuracy, bring in an R^2 value of 0.89944 and the lowest Mean Absolute Percentage Error (MAPE) of 0.03201. In contrast, shorter and longer prediction intervals demonstrated decreased accuracy and increased error rates. The study underscores the importance of selecting optimal prediction intervals for reliable soil moisture forecasting and highlights the potential of GRU models in real-time environmental monitoring. By combining deep learning methodologies and IoT technology, this research contributes to more efficient irrigation practices that can enhance water conservation and improve crop yields, ultimately promoting sustainable agricultural management strategies. Future work may focus on further enhancing model performance and expanding its applicability across diverse agricultural contexts.**

Keywords--- soil moisture, Internet of things, prediction, deep learning, gated recurrent units.

I. INTRODUCTION

Plants are living organisms that require water to grow and develop [1]. They utilize soil as their medium for growth, and fertile soil is essential for optimal plant development. Soil moisture is one of the critical factors influencing plant growth. It plays a vital role in enhancing vegetation and ecosystems, as well as facilitating the nitrogen cycle within the soil [2]. Proper utilization of water for growth is important and crucial. [3]. However, there is still a lot of water wasted in the watering process, as indicated by 40% of water wasted in ineffective irrigation systems. [4]. It is necessary to implement sustainable and effective water management practices to achieve optimal plant health status, crop yields, and minimize water consumption and costs. [5]. To achieve sustainable water management, predictions are essential for the rational use and management of water resources [6].

Recently, numerous studies have been performed to accurately determine and forecast soil moisture levels. One notable article [7], titled "Sustainable Irrigation Requirement Prediction Using Internet of Things and Transfer Learning," discusses a sustainable irrigation system. The primary objective of this article is to predict current and future water requirements over various time intervals, such as 3 hours, 8 hours, 12 hours, 24 hours, and 48 hours. This study combines IoT devices, K-Nearest Neighbors (KNN), cloud storage, Long Short-Term Memory (LSTM), and Adaptive Neuro-Fuzzy Inference System (ANFIS) to perform irrigation system predictions. The findings indicate that all plants require less water compared to manual irrigation methods. This article is highly relevant to the current sensors, as data is collected from agricultural locations using soil moisture sensors; furthermore, LSTM and transfer learning techniques are utilized to enhance the R^2 value.

Another journal article [2] discusses soil moisture prediction conducted using a genetic algorithm combined with LSTM and an attention mechanism. This research integrates LSTM layers, attention mechanisms, and fully connected layers (FCL) for soil moisture prediction based on multivariate time series data. Genetic algorithm (GA) is applied to simultaneously determine the hyperparameters of the proposed network, called GA-LSTM-ATT. These hyperparameters include the number of LSTM layers, hidden units in layers, dropout rates, and learning rates. Through model evaluations using metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), R^2, and Root Mean Squared Percentage Error (RMSPE), this research demonstrates GA-LSTM-ATT method provides a notable solution for soil moisture prediction across various areas.

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The article [8] "An IoT Low-Cost Smart Farming for Enhancing Irrigation Efficiency of Smallholder Farmers" proposes an Edge-IoT Cloud platform driven by deep learning methodologies to monitor and predict farmers' abilities to meet crop water needs when rainfall is lacking. The proposed system allows for the collection of data regarding various environmental physical phenomena, including soil moisture, air temperature, humidity, water level, water flow, and light intensity. This research compares predictive data using LSTM and Gated Recurrent Units (GRU) by using performance metrics such as MAE, Mean Squared Error (MSE), and RMSE to determine the optimal neural network topology for accuracy.

In another study [9] titled "Performance Evaluation of Deep Learning-Based Gated Recurrent Units (GRUs) and Tree-Based Models for Estimating ETo Using Limited Meteorological Variables," the estimation of ETo is performed using tree-based regression and GRU models. This study includes 15 input scenarios consisting of meteorological variables including maximum/minimum temperature, wind speed, maximum/minimum relative humidity, dew point temperature, and sunshine duration.

This research aims to combine soil moisture data with temperature and humidity levels to predict soil moisture for the next minute. Developing this research on IoT devices is crucial for enhancing irrigation efficiency. The study integrates IoT technology, cloud computing, and deep learning methodologies. IoT devices play a significant role in collecting environmental data such as soil moisture, temperature, and air humidity through sensors installed on plants. Afterwards, this data is transmitted via cloud services for processing with deep learning algorithms to generate accurate soil moisture predictions. GRU is selected as the primary method for collecting and processing this data.

This manuscript is arranged as in the following, I. INTRODUCTION contains an introduction to soil moisture prediction and previous related research, II. METHODOLOGY contains soil moisture and deep learning explanation, algorithm, and measurement analysis, III. RESULT contains the result of the research consisting of comparison between various samples.

II. METHODOLOGY

A. *Soil Moisture*

Soil moisture significantly influences plant life [10]. Plants require water during their vegetative stages. Soil moisture is crucial for enhancing vegetation and ecosystems, as well as facilitating the nitrogen cycle within the soil [2]. According to Darlis in [11], the level of fertility is influenced by the intensity of water present. A soil moisture level of 0% indicates a condition where the soil contains no water at all, while a saturated soil condition of 100% is assumed to be filled with water, leaving only minimal air pockets within the soil pores, particularly in the lower layers.

B. *Deep Learning*

Deep learning is an enhanced machine learning that has surpassed its predecessors in terms of capacity and various other aspects [12]. One of the advantages of deep learning is that it can learn large amounts of data. [13]. Currently, deep learning is used in various domains including cybersecurity, natural language processing, bioinformatics, robotics and control, and medical information processing, and many others. Deep learning is commonly used in the agricultural sector [5],[7],[8],[9]

C. *Gated Recurrent Units (GRU)*

Gated Recurrent Units (GRU) are an advancement of Recurrent Neural Networks (RNN). GRUs are designed to understand relationships among data occurring over different time intervals, addressing the vanishing gradient problem, and simplifying the structure of Long Short-Term Memory (LSTM) networks [14]. GRU can be employed for long sequence applications [15].

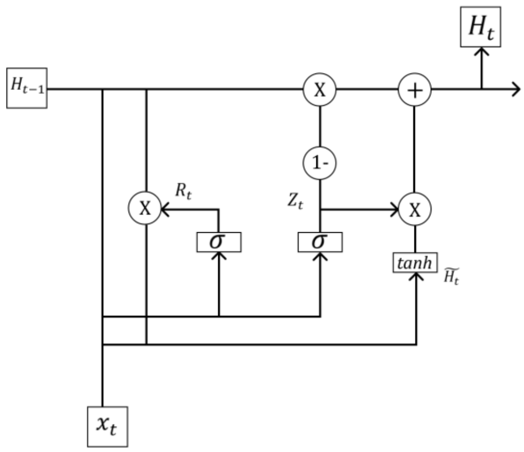

Fig. 1. Structure of GRU

Figure 1 illustrates the structure of GRU, which consists of two input gates: the reset gate $R_t$and the update gate Z_t [14]. The GRU takes the current input x_t and the previous hidden state H_{t-1}, contextualizing the information based on previous states to produce $\widetilde{H_t}$, the new memory. The reset gate R_t determines the importance of the previous hidden state in computing the current hidden state. The update gate Z_t decides how much of the previous hidden state should be retained for the next state to capture long-term dependencies. Finally, the current state H_t is computed using new memory and the previous hidden state based on the results of the update gate [16].

D. *Flowchart*