Sludge Age Prediction Using Deep LSTM Neural Network

Imed Loukam, Aouatef Hellal, Messaoud Djeddou

***Abstract*—** The Sludge Age (SAGE) is an important operating parameter in activated sludge operations. However, predicting it correctly can be problematic due to nonlinear data and variable operating conditions. The goal of this research is to build a long short-term memory (LSTM) network to forecast sludge age (SAGE) using detailed time-series data from a wastewater treatment plant (WWTP). The LSTM architecture has been acknowledged for its ability to handle time series and non-uniform data efficiently. The datasets used to train and evaluate the LSTM model were collected at the Nine Springs Wastewater Treatment Plant near Madison, Wisconsin, United States. Following the use of historical data for training, the proposed LSTM model accurately predicted SAGE, providing potential benefits to WWTP managers in terms of operational performance, system management, and process stability.

***Keywords*—** Activated sludge, LSTM neural networks, Sludge Age, Wastewater Treatment Plant.

I. Introduction

When analytical mathematical models are available, conventional control methods can be effective. However, these models are often lacking in real-world processes, including in the real-time control of Waste Water Treatment Plants (WWTP), which is a challenging but critical task [1]. The significance of Sludge Age (SAGE) as a control parameter lies in its ability to regulate the specific growth rate and physiological state of organisms in the system, as well as the settling properties of the sludge, simultaneously. To control of SAGE, measurements of flow rate and biomass concentrations in the aerator and settler underflow are necessary [2].

A. Predictive modeling techniques have become increasingly popular in various industries in recent years [3]. Long short-term memory (LSTM) is a variant of recurrent neural networks (RNN) and can effectively alleviate the RNN network time delay and gradient vanishing [4] by implementing gating [5]. The interactive operation among these gates makes LSTM have sufficient ability to address the problem of long-term dependencies which general RNNs cannot learn, and it can balance the temporal and nonlinear relationship of data [6].

II. MATERIALS AND METHODS

A. Data Collection

The dataset from 2010 to 2020 was obtained from the Nine Springs Wastewater Treatment Plant (Nine Springs WWTP), Madison, Wisconsin, in the U.S. There are 14 columns of parameters, including influent flow rate, Influent_BOD5, Influent_CBOD5, Influent_TSS, Influent_TKN, Influent_NH3-N, Influent_TP, Influent_VSS, Influent_pH, Effluent_Temp, Effluent_DO, SAGE(t-3), SAGE (t-2), SAGE (t-1) as inputs of the model, and SAGE (t) as single output. The inputs and output were Standardized around a mean of zero and a standard deviation of one. Next, the dataset was divided into a train set (80% of the dataset) and a testing set (20% of the dataset) and subsequently incorporated into the model.

B. Long Short-Term Memory Neural Network

The LSTM neural network is an especially designed kind of recurrent neural network that has the ability to learn and recognize long-term patterns [7]. It has been effectively implemented across a diverse range of issues and is now extensively utilized. The LSTM network is well-suited for handling and forecasting time-series characteristics that have lengthy intervals and delays within the time series [8]–[9]. The LSTM model incorporates three gates, namely the input gate, output gate, and forget gate, which are employed to alter the memory. The input gate and output gate serve the purpose of regulating the input features and output contents, respectively. On the other hand, the forget gate is primarily responsible for determining which memories in the memory unit should be preserved and which memories can be discarded. Fig.1 illustrates the architecture of LSTM.

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Imed Loukam is with the civil department, INFRARES Laboratory, Faculty of Sciences and Technology, University of Souk Ahras,41000 Algeria

Aouatef Hellal is with Research Laboratory in Subterranean and Surface Hydraulics (LARHYSS), Faculty of Sciences and Technology, Mohamed Khider University, Biskra, 07000Algeria.

Messaoud Djeddou is with Hydraulic Development and Environment Laboratory (LAHE), Faculty of Sciences and Technology, Mohamed Khider University, Biskra, 07000 Algeria.

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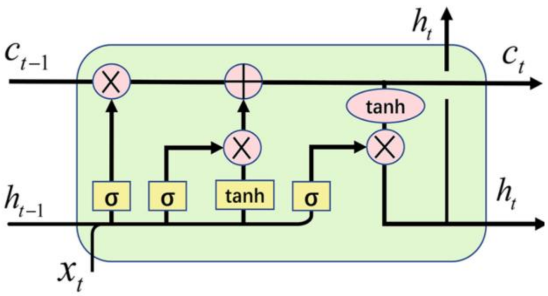

Fig.1. Structure of LSTM neural network.

III. DISCUSSION

Based on the results presented in TABLE I and Fig.2, the model showed a good level of accuracy in predicting Sludge Age (SAGE), even when faced with significant fluctuations in the dataset. Throughout the training phase, the root mean squared error (RMSE) was recorded as 0.5159 day, while the mean absolute error (MAE) was measured at 0.3134 day. Nevertheless, the model's performance during the testing phase fell short of being classified as excellent due to the fact that the RMSE and MAE metrics did not meet a sufficient threshold, which can be attributed to their dependence on the scale of the data. In order to assess the efficacy of a model, it is important to analyze both the training and testing mistakes. The results demonstrate that the suggested LSTM model exhibits good performance in terms of fitting and demonstrates low error metrics.

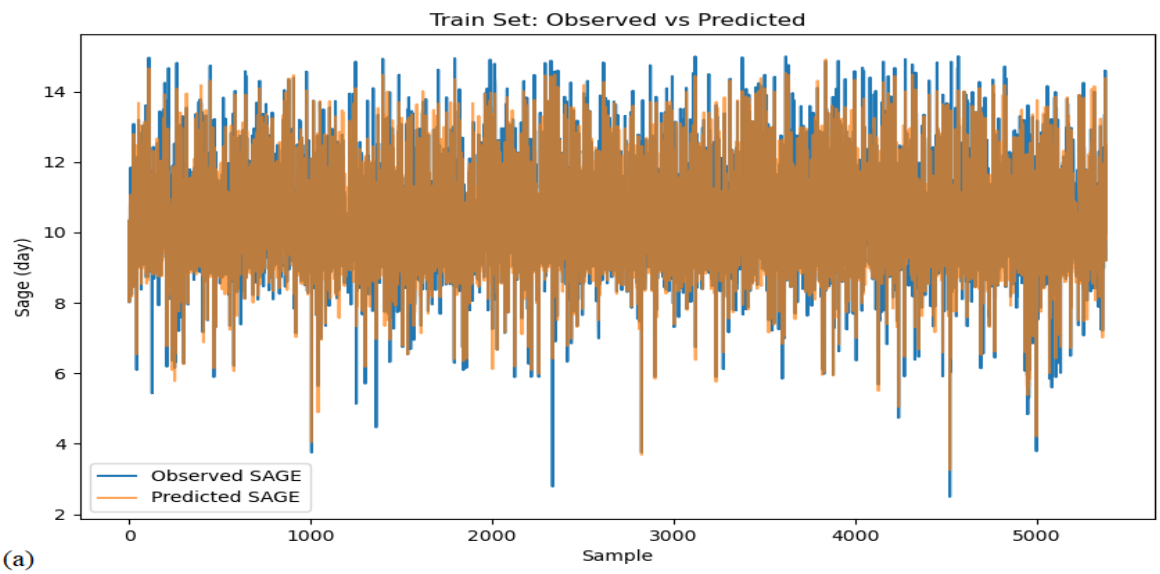

Fig.2 (a)

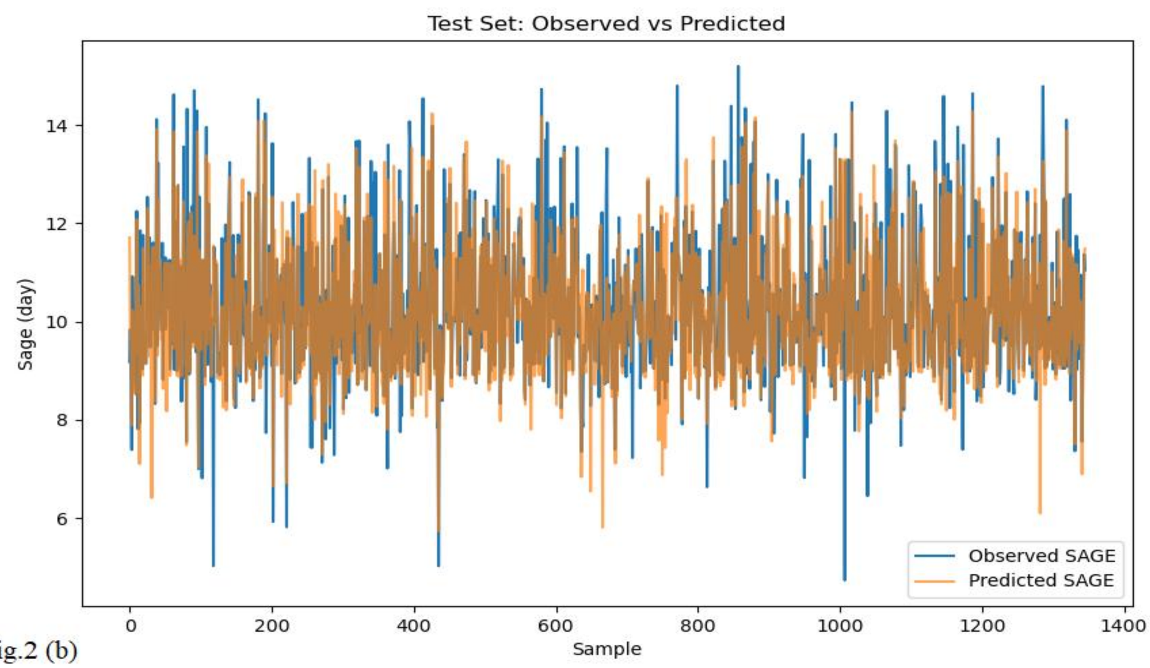

Fig.2 (b)

Fig.2. Comparison of predicted SAGE values of LSTM model with actual SAGE values in the train and test datasets.

TABLE I: PERFORMANCE INDICATORS OF THE LSTM MODEL

	RMSE	MAE	R
Train	0.5159	0.3143	0.9369
Test	0.9407	0.5147	0.7543

IV. CONCLUSION

An accurate determination of sludge age is crucial and essential for the planning, functioning, and regulation of the activated sludge system. After careful investigation, it was concluded that the LSTM model for SAGE prediction, when used in combination with data analysis, is appropriate for WWTP operations.

The charts depicted in Fig.2 demonstrate that the LSTM model yields substantially diminished error values, with the two lines exhibiting a high degree of alignment. The findings indicate that the LSTM architecture is well-suited for efficiently handling common variations in the activated sludge system. Furthermore, the meticulous choice of relevant data is essential for the process of data analysis.

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Dr. Imed LOUKAM
Laboratory of Management, Maintenance and Rehabilitation of Facilities and Urban Infrastructure (INFRARES), Faculty of Sciences and Technology , University of Souk Ahras, Algeria.

He was born in 1973, Souk-Ahras, Algeria. He received the Engineer diploma from the University of Annaba, Algeria, in 1995 and the Ph.D.degrees from hydraulic Department from University of Annaba, Algeria.

Dr Loukam is a Assistant Professor at the civil department, University of Souk-Ahras, Algeria. Its research area is drinking water treatment, wastewater purification and reuse, hydraulic flows.

Pr. Messaoud Djeddou
Laboratory of Hydraulic Developments and Environment (LAHE), Faculty of Sciences and Technology, Mohamed Khider University, Biskra, Algeria.

He was born in Biskra, Algeria, in 1971. He received the Engineer diploma from the Hydraulic Department, Biskra University,Algeria, in 1996 and the M.S. from National High School of Water Engineering and Environment, Strasbourg, France and Ph.D.degrees from Biskra University, Algeria, in 2005 and 2014, respectively.

Pr. Djeddou is a Full Professor at the Hydraulic Department, Oum El-Bouaghi University, Algeria. His research interests include application of AI, ML, ANN's, Hybrid-modelling, and Data mining in Thermo-Hydraulics, Water engineering and Healthcare data.

Dr. Aouatef Hellal
Research Laboratory in Subterranean and Surface Hydraulics (LARHYSS), Faculty of Sciences and Technology, MohamedKhider University, Biskra, Algeria.

She was born in Biskra, Algeria, in 1978. He received the Engineer diploma and Magister Degree from the Hydraulic Department, Biskra University,Algeria, in 2005, 2008 respectively, and Ph.D.degrees from Biskra University, Algeria, in 2019.

Dr. Hellal is an Assistant Professor at the Hydraulic Department, Faculty of Sciences and Applied sciences at Oum El-Bouaghi University, Algeria. His research interests include Chlorination, water treatment, Advanced oxidation, and application of Machine Learning.