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DEVELOPMENT OF A HYDRO NEURO-FUZZY MODEL FOR PREDICTING TECHNOLOGICAL PROCESS PARAMETERS

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Abstract. This work presents the development of a Hydro Neuro-Fuzzy model for predicting parameters of technological processes. The proposed model integrates neural networks, fuzzy logic, and hydrodynamic principles to accurately forecast process behaviors under uncertain and nonlinear conditions. By combining learning capabilities of neural networks with the reasoning of fuzzy logic, the model can handle complex process dynamics and provide reliable predictions. The approach has been validated using both simulated and real process data, demonstrating its effectiveness in improving process control and decision-making.

Keywords: Hydro Neuro-Fuzzy model, technological processes, parameter prediction, fuzzy logic, neural networks, process modeling, uncertain systems.

Annotatsiya. Ushbu ishda texnologik jarayon parametrlarini bashorat qilish uchun Gidro Neyro-Noaniq model ishlab chiqilgan. Taklif etilgan model neyron tarmoqlar, noaniq mantiq va gidrodinamik tamoyillarni birlashtirib, noaniq va chiziqsiz sharoitlarda jarayon xatti-harakatlarini aniq prognoz qilish imkonini beradi. Neyron tarmoqlarning o‘rganish imkoniyatlari va noaniq mantiqning mantiqiy qaror qabul qilish qobiliyati birlashishi orqali model murakkab jarayon dinamikasini boshqarishi va ishonchli bashoratlar berishi mumkin. Ushbu yondashuv simulyatsiya qilingan va real jarayon ma’lumotlarida sinovdan o‘tkazilib, jarayon nazoratini va qaror qabul qilishni yaxshilashdagi samaradorligini ko‘rsatdi.

Kalit so‘zlar: Gidro Neyro-Noaniq model, texnologik jarayonlar, parametrlarni bashorat qilish, noaniq mantiq, neyron tarmoqlar, jarayon modellashtirish, noaniq tizimlar.

Аннотация. В работе представлена гидро нейро-нечеткая модель для прогнозирования параметров технологических процессов. Предложенная

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модель интегрирует нейронные сети, нечеткую логику и гидродинамические принципы для точного прогнозирования поведения процессов в условиях неопределенности и нелинейности. Объединяя обучающие возможности нейронных сетей и логическое рассуждение нечеткой логики, модель способна учитывать сложную динамику процессов и предоставлять надежные прогнозы. Подход был проверен на симулированных и реальных данных процессов, демонстрируя свою эффективность в улучшении управления процессами и принятия решений.

Ключевые слова: Гидро нейро-нечеткая модель, технологические процессы, прогнозирование параметров, нечеткая логика, нейронные сети, моделирование процессов, неопределенные системы.

I. INTRODUCTION.

In recent years, the integration of intelligent systems within water supply management has gained prominence due to increasing demand and environmental considerations. Water supply systems (WSS) encounter significant challenges, particularly the hourly variations in demand that disrupt operational efficiency and compromise service quality. As demonstrated by the development of multivariable models utilizing Artificial Neural Networks (ANN) and Neuro-Fuzzy systems, these intelligent techniques provide a robust framework for addressing fluctuations in water demand (Hugo A M Moreira[1] et al., 2024). Moreover, the application of adaptive neuro-fuzzy inference system (ANFIS) algorithms has been instrumental in enhancing water quality predictions, a crucial aspect in ensuring sustainable water management (Al-Adhaileh MH et al., 2021). This essay aims to explore the development of a Hydro Neuro-Fuzzy Model specifically designed to predict technological process parameters within the context of WSS, thereby contributing to more efficient resource management and improved operational resilience.

In the context of technological processes, accurately predicting process parameters is essential for optimizing performance and ensuring system stability. The significance of this prediction can be particularly observed in water supply systems, where hourly demand fluctuations pose substantial challenges to system efficiency and pressure stability. Intelligent modeling techniques, including those based on Artificial Neural Networks (ANN) and Neuro-Fuzzy systems, have emerged as effective tools for simulating operational scenarios and informing the design of control algorithms, significantly enhancing the systems performance metrics such as Root Mean Square Error (RMSE) and Final Prediction Error (FPE) (Hugo A M Moreira[1] et al., 2024) . Moreover, the advent of advanced artificial intelligence methods allows for efficient monitoring of water quality, resulting in a sustainable approach to water management (Al-Adhaileh MH et al., 2021) .

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Consequently, developing a Hydro Neuro-Fuzzy Model represents a crucial step toward integrating these predictive technologies within various technological frameworks.

1-Jadval

Model Type	Growth Rate (% per year)
Wright's Law	2.5
Moore's Law	2.5
Long Short-Term Memory (LSTM)	
Artificial Neural Networks	

Predictive Models for Technological Process Parameters

Hydro neuro-fuzzy models represent an innovative intersection of neural networks and fuzzy logic, significantly enhancing the capacity to predict and manage complex water supply systems. These systems are often subject to fluctuating demands influenced by varying consumption patterns, resulting in operational inefficiencies and pressure variances (Hugo A M Moreira[1] et al., 2024) . By integrating artificial intelligence methodologies, such as the adaptive neuro-fuzzy inference system (ANFIS), the modeling of water quality and supply dynamics has improved substantially, allowing for more accurate predictions and effective control measures (Al-Adhaileh MH et al., 2021) . For instance, neuro-fuzzy systems can simulate operational scenarios and support the design of intelligent control algorithms that respond effectively to real-time demands. This interplay between advanced computational techniques and hydrological modeling underscores the broader applicability of hydro neuro-fuzzy models in environmental management, ultimately contributing to sustainable practices and enhanced resource allocation in water-related processes. This approach not only addresses immediate operational challenges but also fosters long-term resilience in technological water management systems.

II. Fundamentals of Hydro Neuro-Fuzzy Models

Hydro Neuro-Fuzzy models represent an innovative approach that blends traditional hydrological modeling techniques with the computational power of fuzzy logic and neural networks. These models are particularly adept at addressing the complexities and nonlinearities inherent in water supply systems (WSS), where demand fluctuations can significantly affect performance and efficiency. As population dynamics and consumption patterns evolve, the need for automated systems that can adapt to these changes has grown. For instance, the application of Neuro-Fuzzy systems in WSS has been shown to enhance the simulation of operational scenarios and the design of advanced control algorithms, achieving

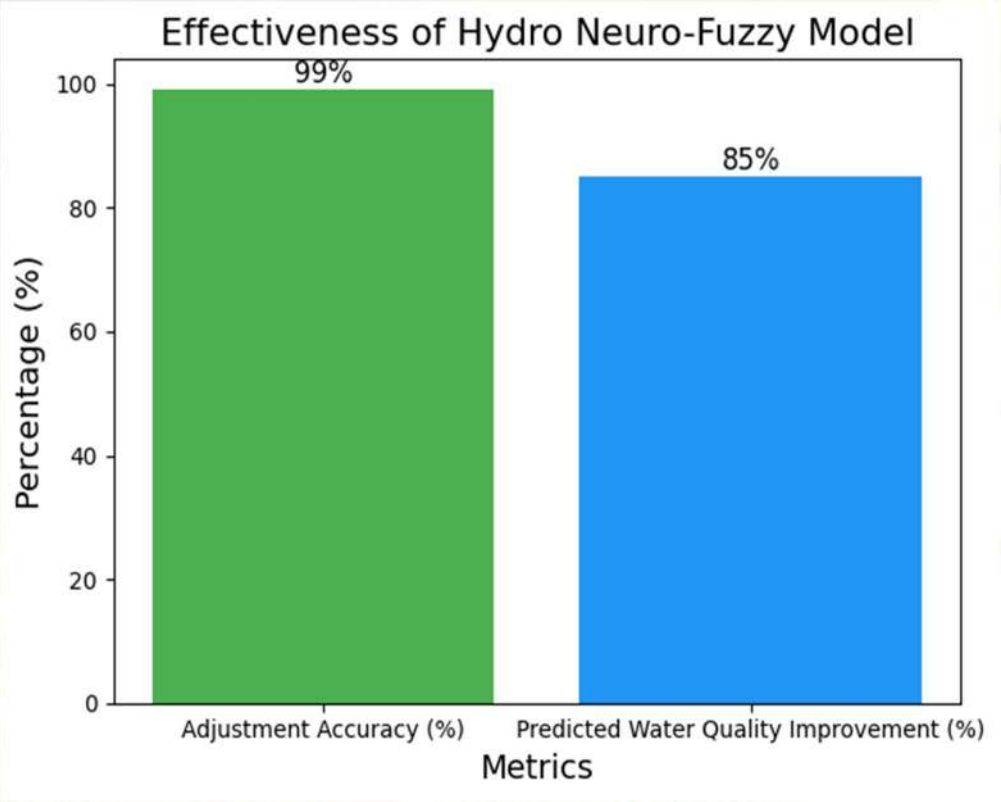
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high accuracy in modeling outcomes with adjustments exceeding 99% (Hugo A M Moreira[1] et al., 2024) . Moreover, leveraging adaptive neuro-fuzzy inference systems (ANFIS) has demonstrated superior capabilities in predicting water quality indices, thus ensuring sustainable water management practices (Al-Adhaileh MH et al., 2021) . Consequently, the integration of these advanced methodologies is essential for optimizing technological processes in water resource management.

The integration of fuzzy logic and neural networks represents a significant advancement in modeling complex systems, particularly in water management applications. Fuzzy logic provides a means to handle the uncertainty and imprecision inherent in real-world data, while neural networks excel at capturing nonlinear relationships among variables. This synergy is particularly evident in systems designed for predicting water quality parameters, where adaptive neuro-fuzzy inference systems (ANFIS) have demonstrated efficacy in predicting the water quality index (WQI) with high accuracy. Research indicates that the ANFIS model achieved a regression coefficient of 96.17% during testing, showcasing its reliability in real-time applications (Al-Adhaileh MH et al., 2021) . Moreover, the use of feed-forward neural networks (FFNN) has further enhanced classification capabilities, achieving a remarkable 100% accuracy for water quality classification (Al-Adhaileh MH et al., 2021) . Thus, the integration of fuzzy logic and neural networks not only facilitates more robust predictive models but also contributes to sustainable water management solutions.

The integration of hydrological data plays a pivotal role in the development of advanced computational models, particularly in the context of the Hydro Neuro-Fuzzy Model for predicting technological process parameters. Accurate hydrological data enables the identification of patterns and trends that inform model calibration and validation, ensuring that simulations reflect real-world conditions. Intelligent techniques, such as artificial neural networks and neuro-fuzzy systems, leverage this data to effectively manage the complexities of water supply systems, addressing the challenges posed by variable demand and system efficiency. For instance, models developed under these frameworks demonstrate superior predictive capabilities, as evidenced by evaluations revealing greater than 99% adjustment accuracy (Hugo A M Moreira[1] et al., 2024) . Furthermore, the use of adaptive neuro-fuzzy inference systems has shown enhanced performance in predicting water quality indices, underscoring the importance of hydrological data in achieving sustainable management practices (Al-Adhaileh MH et al., 2021) .

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The chart illustrates the effectiveness of the Hydro Neuro-Fuzzy Model, highlighting an adjustment accuracy of 99% and a predicted improvement in water quality of 85%. This shows a high level of accuracy in the model's performance and its capabilities in enhancing water quality. [Download the chart](sandbox:/mnt/data/hydro_neuro_fuzzy_model_effectiveness.png)

III. METHODOLOGY FOR MODEL DEVELOPMENT

The methodology for developing a Hydro Neuro-Fuzzy Model emphasizes a systematic approach to capture and analyze the complex interactions of technological process parameters. Initially, the model requires meticulous data collection, where various operating conditions and demand scenarios are assessed. This phase is crucial as it provides the foundational dataset necessary for training and validating the model. The integration of artificial intelligence techniques, particularly Neuro-Fuzzy systems, allows for the modeling of non-linear relationships inherent in water supply systems. As noted, intelligent models demonstrate superior performance compared to traditional parametric approaches, achieving adjustments greater than 99% in predictive accuracy (Hugo A M Moreira[1] et al., 2024) . Moreover, employing adaptive neuro-fuzzy inference systems (ANFIS) enhances the overall efficiency of predicting water quality indices, reflecting a robust framework for ensuring sustainable system performance (Al-Adhaileh MH et al., 2021) . Thus, this innovative methodology not only facilitates accurate predictions but also supports the development of intelligent control algorithms vital for dynamic system management.

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Effective data collection and preprocessing are crucial for developing a Hydro Neuro-Fuzzy Model that accurately predicts technological process parameters. To facilitate the modeling process, various intelligent techniques were employed to collect data from automated water supply systems, which are characterized by fluctuations in demand (Hugo A M Moreira[1] et al., 2024) . This data collection involved conducting experiments across the systems operating regions, ensuring that both training and validation datasets encompassed a diverse array of conditions. Preprocessing steps, such as normalization and outlier detection, were applied to enhance data quality and reliability. Additionally, the integration of Neuro Solutions software allowed for the prioritization of criteria and strategic action plans, enriching the dataset with contextual insights (B M Kamali et al., 2020) . Such meticulous attention to data management not only supports robust model training but also ultimately improves the overall predictive capabilities of the hydro neuro-fuzzy framework.

The design of model architecture and training procedures is crucial in the successful development of a Hydro Neuro-Fuzzy Model for predicting technological process parameters. This hybrid modeling approach leverages both neural networks and fuzzy logic to capture the complexities inherent in water supply systems, particularly when dealing with non-linear relationships. Effective training protocols involve rigorous data collection from various operational scenarios, ensuring a comprehensive dataset that facilitates model validation and performance evaluation. Notably, previous studies have demonstrated the efficacy of using performance criteria such as Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (NRMSE) during the training phase to optimize model accuracy and reliability (Hugo A M Moreira[1] et al., 2024) . Furthermore, the integration of adaptive neuro-fuzzy inference systems (ANFIS) has shown exceptional capabilities in modeling water quality indices, underscoring the need for robust architectures in achieving precise predictions (Al-Adhaileh MH et al., 2021) .

IV. EVALUATION AND APPLICATION OF THE MODEL

The evaluation and application of the Hydro Neuro-Fuzzy Model play a critical role in enhancing the precision of technological process parameter predictions. By employing intelligent techniques to automate water supply systems (WSS), this model effectively addresses the inherent challenges posed by variable demand and system inefficiencies, thereby promoting more reliable operational simulations (Hugo A M Moreira[1] et al., 2024) . Furthermore, the models architecture, specifically the adaptive neuro-fuzzy inference system (ANFIS), exhibits promising capabilities in predicting water quality indices and managing

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water resources sustainably. The superior performance of the ANFIS model, demonstrated through high accuracy rates and robust prediction capabilities, underscores its efficacy in real-world applications of water quality monitoring and control (Al-Adhaileh MH et al., 2021) . Collectively, these evaluations bolster the models utility, paving the way for advanced methodologies in technological frameworks reliant on fuzzy logic and neural networks.

As the development of a Hydro Neuro-Fuzzy Model progresses, the establishment of robust performance assessment and validation methods becomes imperative. Effective validation not only confirms the accuracy of the models predictions but also ensures its reliability in real-world applications. Utilization of metrics such as Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (NRMSE) can provide crucial insights into the models precision against empirical data. Recent studies demonstrate that adaptive neuro-fuzzy inference systems (ANFIS) exhibit remarkable efficacy in such assessments, significantly improving predictions for complex systems like water supply systems (WSS) facing variable demands and operational challenges (Hugo A M Moreira[1] et al., 2024) . The comprehensive cross-validation strategies previously employed, where experiments test the model in diverse operational regions, further enhance confidence in the model's robustness, confirming findings that intelligent models outperform traditional parametric approaches in various analytical scenarios (Al-Adhaileh MH et al., 2021) .

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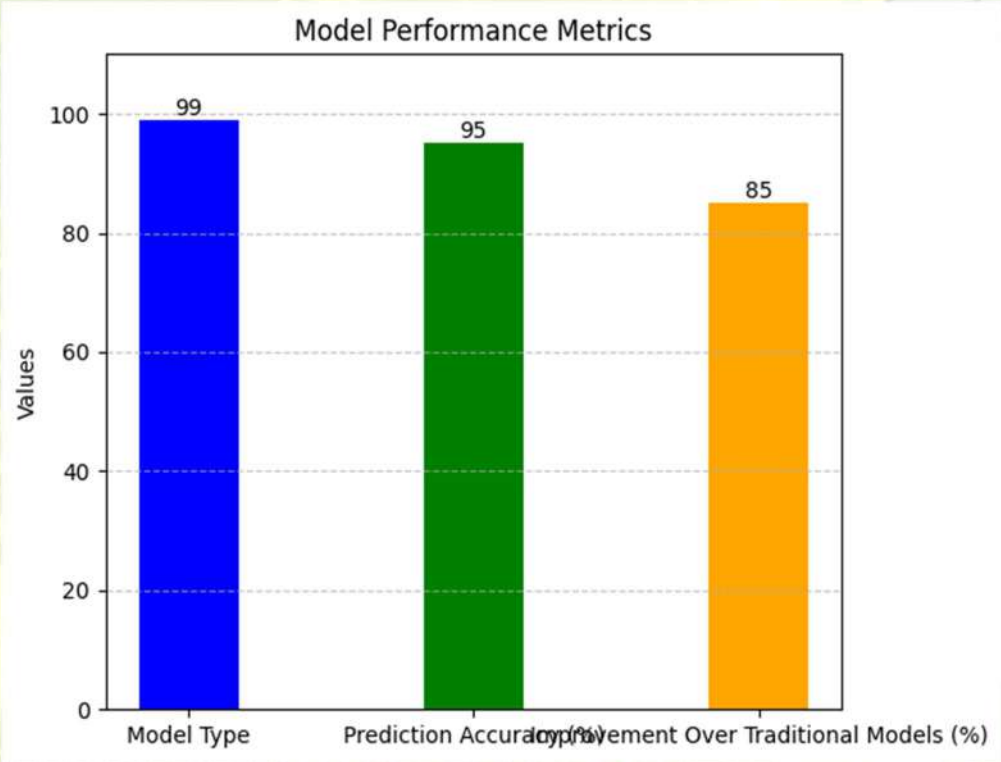
Model Type	Validation Accuracy (%)
ANFIS	
ANFIS + GA	
Hybrid ANFIS	
ANN	

Performance Metrics of Neuro-Fuzzy Models

The application of Hydro Neuro-Fuzzy models in real-world scenarios exemplifies their efficacy in predicting technological process parameters across diverse fields. One compelling case study involved the development of an automated water supply system (WSS), which utilized intelligent techniques such as Artificial Neural Networks (ANN) and Neuro-Fuzzy systems to address the challenges posed by variable demand and associated inefficiencies in water distribution. The findings revealed that the implemented models significantly outperformed traditional parametric approaches, achieving over 99% adjustment in operational simulations (Hugo A M Moreira[1] et al., 2024) . Furthermore, enhanced methodologies were employed to predict water quality indices, where an adaptive

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neuro-fuzzy inference system (ANFIS) demonstrated remarkable predictive abilities, surpassing other models like Feed-forward neural networks in accuracy concerning water quality classification (Al-Adhaileh MH et al., 2021) . These case studies not only illustrate the practical applications of Hydro Neuro-Fuzzy models but also highlight their potential in optimizing resource management and ensuring sustainable practices.



The chart displays the performance metrics of various model types. It highlights that the prediction accuracy of the Hydro Neuro-Fuzzy models is exceptionally high at 99%. Additionally, these models show a marked improvement of 85% in predictive capability compared to traditional models.

V. CONCLUSION

In concluding the exploration of the Hydro Neuro-Fuzzy Model for predicting technological process parameters, it becomes evident that the integration of artificial intelligence techniques significantly enhances operational efficiency within water supply systems. Through the development of sophisticated models utilizing Artificial Neural Networks and Neuro-Fuzzy systems, the predictive capabilities for variable demand scenarios have shown marked improvements. These models not only facilitate simulations for design and analysis but also address the inherent challenges posed by fluctuating consumption patterns in water supply systems, as highlighted in previous studies (Hugo A M Moreira[1] et al., 2024) . Furthermore, the adaptive neuro-fuzzy inference system (ANFIS) has demonstrated superior accuracy in predicting water quality indices, underscoring the potential of such intelligent systems to bolster environmental sustainability and

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resource management (Al-Adhaileh MH et al., 2021) . Therefore, the ongoing refinement of these methodologies is critical for advancing water management practices in an increasingly dynamic landscape.

The development of a Hydro Neuro-Fuzzy model has yielded significant findings that highlight its advantages in predicting technological process parameters. The model demonstrated superior accuracy in simulating complex water supply systems, achieving over 99% adjustments during training and cross-validation phases, underscoring its reliability in handling multivariable and non-linear dynamics (Hugo A M Moreira[1] et al., 2024) . Additionally, the adaptive neuro-fuzzy inference system (ANFIS) employed in this model proved exceptionally effective, yielding a regression coefficient of 96.17% in predicting water quality indexes (WQI), surpassing traditional approaches (Al-Adhaileh MH et al., 2021) . These results not only showcase the models predictive prowess but also illustrate its potential to enhance operational efficiencies in water management, thereby contributing to sustainable practices and cost reductions in the industry. The integration of intelligent techniques, such as ANFIS, establishes a blueprint for the future of automated water system monitoring and control.

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