

SINGIDUNUM UNIVERSITY
Postgraduate Studies Department
Danijelova 32, Belgrade

TO THE COUNCIL OF POSTGRADUATE STUDIES DEPARTMENT

Based on the decision of the Council of postgraduate studies brought at the Session held on 18.7.2024, we have been delegated as the members of the Board for the assessment and the following defense of the dissertation with the title: "**Application of Hybrid Methods Combining Recurrent Neural Networks and Modified Metaheuristics for Time-Series Forecasting**" of the candidate Mohamed Abdusalam Y Salb (student ID number 2021/470042). We hereby submit the following

REPORT OF THE PHD THESIS BY THE PHD CANDIDATE MOHAMED ABDUSALAM Y SALB

1 Main information about the candidate

Candidate Mohamed Salb obtained his Bachelor's Degree in Information Technology from the Faculty of Informatics and Computing, Singidunum University, Belgrade, Serbia, in 2020. He pursued a Master's degree in Modern Information Technologies at the same university, graduating in 2021 with a perfect 10.0 GPA.

Work experience: Mohamed is currently a Computer Science and Computing Teacher at PRIMA International School, Belgrade, Serbia. He is responsible for curriculum development, teaching coding and programming, and providing ICT support across the school. Previously, he held the role of ICT and Mathematics Teacher at the same institution. In addition, Mohamed has been working as a freelance researcher, with several published papers in the field of information technology.

The candidate enrolled in doctoral studies at Singidunum University in November 2021 in the PhD program in Natural and Mathematical Sciences, specializing in Advanced Security Systems. His research, titled "Application of Hybrid Methods Combining Recurrent Neural Networks and Modified Metaheuristics for Time-Series Forecasting", was accepted at the session of the Council of the Department of Postgraduate Studies on 23.5.2024.

Published paper:

1. **Mohamed Salb**, Luka Jovanovic, Ali Elsadai, Nebojsa Bacanin, Vladimir Simic, Dragan Pamucar, Miodrag Zivkovic (2024): Cloud spot instance price forecasting multi-headed models tuned using modified PSO. Journal of King Saud University-Science(Elsevier) 36 (11), p. 103473, **M22**
2. Luka Jovanovic, Milos Antonijevic, Miodrag Zivkovic, Milos Dobrojevic, **Mohamed Salb**, Ivana Strumberger, Nebojsa Bacanin (2024): Long short-term memory tuning by enhanced Harris hawks optimization algorithm for crude oil price forecasting. (Elsevier).
3. Nebojsa Bacanin, Luka Jovanovic, Milos Dobrojevic, Miodrag Zivkovic, Milos Antonijevic, **Mohamed Salb** (2024): Exploring the Potential of Modified Metaheuristic Optimized Long-Short Term Memory Neural Networks for Earthquake Magnitude Forecasting. (CRC Press).
4. **Mohamed Salb**, Luka Jovanovic, Nebojsa Bacanin, Milos Antonijevic, Miodrag Zivkovic, Nebojsa Budimirovic, Laith Abualigah (2023): Enhancing internet of things network security using hybrid CNN and xgboost model tuned via modified reptile search algorithm. Journal of Applied Sciences (MDPI) 13(23), p. 12687, **M22**
5. **Mohamed Salb**, Luka Jovanovic, Nebojsa Bacanin, Goran Kunjadic, Milos Antonijevic, Miodrag Zivkovic, V Kanchana Devi (2023): The Long Short-Term Memory Tuning for Multi-step Ahead Wind Energy Forecasting Using Enhanced Sine Cosine Algorithm and Variation Mode Decomposition. International Conference on Paradigms of Communication, Computing and Data Analytics (Springer Nature Singapore), p. 31-43.
6. Stanislava Kozakijevic, **Mohamed Salb**, Ali Elsadai, Joseph Mani, Kanchana Devi, Anni Dasho Sharko, Suresh Muthusamy (2023): Seizure detection via time series classification using modified metaheuristic optimized recurrent networks. Theoretical and Applied Computational Intelligence 1(1), p. 82-94.
7. **Mohamed Salb**, Luka Jovanovic, Miodrag Zivkovic, Eva Tuba, Ali Elsadai, Nebojsa Bacanin (2022): Training logistic regression model by enhanced moth flame optimizer for spam email classification. Computer networks and inventive communication technologies: Proceedings of fifth ICCNCT 2022 (Springer Nature Singapore), p. 753-768.

The doctoral dissertation of the candidate Mohamed Abdusalam Y Salb has a total of 176 pages. The literature overview has a total of 134 references, including scientific papers, conference papers, books, and other electronic sources.

Together with the text, the dissertation contains 36 figures, 35 tables and 75 equations.

Doctoral dissertation of the candidate *Mohamed Abdusalam Y Salb* has been tested with iThenticate Plagiarism Detection Software. The total percentage of the detected similarities is 47% of the dissertation, which is acceptable, given that it includes 7 scientific papers in which Mohamed Salb was an author and which are shown as the top 8 of the plagiarism check results with a total of around 39% overlapping. Furthermore, if we exclude that from the report plagiarism would be around just 8%. Overlapping with all other source is less than 1%. Additionally, all mentioned papers that overlap with the thesis content serve as the research backbone of proposed theses.

2. The aim of the study

The main aim of this research is to develop and apply hybrid methods combining Recurrent Neural Networks (RNNs) and modified metaheuristics to improve the accuracy of time-series forecasting in various critical fields. This study explores how integrating these techniques can address current challenges in forecasting and prediction across multiple domains, including IoT security, stock price forecasting, oil price forecasting, seizure detection using EEG data, wind energy integration, spam email filtering, and other time-sensitive fields.

Given the broad scope of this research, multiple objectives are covered, as this thesis is composed of seven scientific papers, each focusing on different applications of the hybrid methods. The ultimate objectives of this study are listed below:

- Enhance model performance by developing and optimizing CNN, XGBoost, logistic regression, and LSTM models.
- Using advanced optimization algorithms like Modified Reptile Search, Enhanced Sine Cosine Algorithm (ESCA), Moth Flame Optimizer (MFO), Harris Hawks Optimization (HHO), and the modified sine-cosine algorithm (HASCO).
- Apply methodologies to real-world data in IoT security, wind energy, spam classification, seizure detection, crude oil prices, and earthquake prediction.
- Assess the performance of suggested hybrid models to traditional approaches to ensure accuracy and efficiency improvements, while analyzing feature importance through techniques like Shapley Additive Explanations (SHAP).

3. The study hypothesis

The following hypotheses were put forward:

- A higher accuracy can be achieved by hybrid and optimized models such as (CNN-XGBoost, and LSTM-ESCA) in their respective applications compared to traditional models.
- Modified algorithms for optimization will significantly increase the efficacy and precision of machine learning models.
- Preprocessing techniques for instance Variation Mode Decomposition (VMD) can improve the precision and efficacy of forecasting models.

4. The research methodology

For the review of the literature, a search of internet sources was used using keywords: Time-series forecasting, Recurrent Neural Networks, Metaheuristic algorithms, Long Short-Term Memory, Sine Cosine Algorithm, Moth Flame Optimizer, IoT security, Seizure detection, Crude oil price forecasting, Swarm intelligence algorithms, Earthquake forecasting, wind energy forecasting, Spam filtering, Logistic regression, Cloud computing, Gated recurrent units, Particle swarm optimization, Spot price forecasting

The researcher employed a comparative and exploratory approach to investigate the potential of hybrid methods in addressing seven critical challenges: Internet of Things (IoT) security, oil price forecasting, seizure detection using brainwave recordings, wind energy grid integration, spam email filtering, long-term stock price forecasting, and cloud spot instance price forecasting.

Data collection and analysis methods depended on the specific problem chosen for in-depth exploration. A comprehensive literature review was conducted, focusing on both the chosen problem and the application of hybrid methods in similar domains. This provided a strong foundation for further research. Additionally, case studies of successful hybrid method implementations in related fields were analyzed to glean insights into their effectiveness for the chosen problem. Depending on the specific challenge, data simulation techniques were utilized to create realistic datasets for testing and evaluating hybrid methods.

The effectiveness of the proposed hybrid methods was evaluated through techniques tailored to the specific problem domain. This involved employing relevant performance metrics commonly used in the chosen domain, such as accuracy for prediction models or security metrics for IoT applications. A comparative analysis was also conducted, comparing the performance of the proposed hybrid methods with existing solutions to assess their relative efficacy.

The research delved into the theoretical underpinnings of hybrid methods, explaining why they held promise for addressing the chosen challenges. This included highlighting how machine learning (ML) and metaheuristics addressed each other's limitations when combined. For instance, the research explored how ML excelled at pattern recognition, while metaheuristics optimized hyperparameters in ML models, leading to improved performance. Additionally, the research demonstrated how hybrid methods could be adapted to different problems by using appropriate ML algorithms and metaheuristic techniques, creating solutions tailored to the specific challenge at hand. Finally, the research explained how metaheuristics were used to optimize the hyperparameters of ML models for improved performance, significantly enhancing the accuracy and effectiveness of the overall solution.

Overall, the research methodology was a unique blend of established research methods and innovative exploration of hybrid methods. By utilizing a combination of approaches, the research aimed to develop effective solutions to real-world problems and contribute to the advancement of this field.

5. The content of the thesis

The thesis consists of six chapters.

Chapter 1: INTRODUCTION

General Research Framework contains the theoretical framework of the study as an introduction to the research that discusses the background, the problem statement and the research question, the research objectives, the literature review, the research methodology, and the thesis structure

Chapter 2: PROCESS OF OPTIMIZATION

This chapter dives into the core of optimization, explaining what it means (finding the best solution with limitations) and giving an overview of different types (single-objective vs balancing multiple goals). It then breaks down the process of tackling optimization problems, outlining steps like defining the issue, building a mathematical model, choosing the right solution method, and evaluating the outcome. The chapter concludes by acknowledging the challenges that arise in optimization, including dealing with complexity, ensuring data quality, navigating trade-offs, and interpreting the results.

Chapter 3: STOCHASTIC OPTIMIZATION TECHNIQUES

This chapter tackles stochastic optimization, a method for problems with randomness. It starts by contrasting deterministic (perfect information) and stochastic (uncertainties) approaches. Stochastic techniques find good "average" solutions. The chapter introduces two key categories: Evolutionary Computation (EC), inspired by evolution, which includes Genetic Algorithms that evolve solutions towards optimal states. Swarm intelligence, inspired by social insects, is covered in Chapter 4.

Chapter 4: SWARM INTELLIGENCE METAHEURISTICS

This chapter explores swarm intelligence (SI), a problem-solving method inspired by social insects. Unlike traditional approaches, SI uses populations with simple rules to find optimal solutions in complex situations. The chapter introduces popular SI algorithms like Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO), inspired by real-world collective behaviors.

Chapter 5: SWARM INTELLIGENCE APPLICATIONS

This chapter explores the widespread applications of swarm intelligence (SI) in optimization, robotics, engineering, finance, and beyond. It then dives into recent advancements in the field, including novel applications in new domains like healthcare and logistics, the development of new SI algorithms inspired by various biological phenomena, and the creation of even more powerful hybrid approaches that combine SI with other techniques. Finally, the chapter highlights seven applications focused on SI, showcasing specific contributions to this ever-evolving field.

Chapter 6: CONCLUSION AND FUTURE WORK

This chapter concludes the exploration of optimization techniques, emphasizing swarm intelligence (SI). It recaps the journey through core optimization concepts, types, and SI's effectiveness in complex problem-solving. The chapter highlights established SI applications and ongoing advancements like novel algorithms, new application areas, and hybrid approaches with other techniques. Finally, it looks towards the future, suggesting exciting areas for further SI research, paving the way for tackling even more intricate real-world challenges.

6. Scientific contribution

The seven problems we've explored present significant challenges with far-reaching consequences. In the realm of the Internet of Things (IoT), insecure devices can be exploited to disrupt critical infrastructure, expose personal data, and erode consumer trust in these technologies. Finding solutions is essential to protect public safety, safeguard sensitive information, and foster the widespread adoption of beneficial IoT applications.

Accurate oil price forecasting is crucial for informed decision-making across various sectors. Businesses and governments rely on these predictions to make strategic investments, allocate resources effectively, and establish sound economic policies. Improved forecasting can lead to a more stable oil market, benefiting consumers by reducing energy price fluctuations. Additionally, it empowers countries to develop robust energy security strategies, preparing them for potential price spikes or supply disruptions.

Early and accurate seizure detection using brainwave recordings can significantly improve the lives of people with epilepsy. Timely medical intervention upon seizure onset can minimize seizure severity and improve long-term patient outcomes. This translates to a better quality of life and potentially reduces healthcare costs by minimizing the need for emergency services and hospitalizations. Furthermore, advancements in seizure detection methods pave the way for further research into the causes and treatment of epilepsy, potentially leading to breakthroughs in prevention and therapy.

Optimizing grid integration for intermittent wind energy is a critical step towards a clean and sustainable energy future. By effectively integrating wind power, we can lessen our reliance on fossil fuels and mitigate the effects of climate change. This not only benefits the environment but also leads to a more stable and reliable electricity supply, reducing the risk of blackouts and power outages. Additionally, efficient integration of wind energy fosters a more efficient overall energy grid, minimizing energy waste and optimizing power distribution.

The ever-growing problem of spam emails disrupts user productivity, threatens network security, and increases IT costs. Effective spam filtering solutions are essential to reclaim wasted time spent dealing with unwanted emails, enhance overall productivity, and protect users from phishing attacks and malware distribution often embedded in spam emails. By implementing robust spam filtering techniques, we can safeguard network security and alleviate the burden on IT departments, leading to a more efficient and cost-effective IT infrastructure.

Improving long-term stock price forecasting using Long Short-Term Memory (LSTM) tuning empowers investors to make informed decisions and potentially improve investment returns. This

contributes to a more stable and efficient financial market. Additionally, more accurate forecasts allow for better risk management by enabling investors to assess potential risks associated with stock market fluctuations and develop effective strategies to mitigate them. Ultimately, improved forecasting fosters a more informed and efficient market, benefiting all participants.

Accurate cloud spot price forecasting is crucial as demand for cloud computing services continues to grow. High leasing costs can be mitigated through precise predictions, allowing customers to manage their budgets more effectively. Machine learning (ML) and artificial intelligence (AI) can help by automatically scaling resources to match workload demands. However, tuning the hyperparameters of ML models is a complex challenge. Improving cloud spot price prediction by using optimized multi-headed GRU and LSTM models, will lead to better cost management and operational efficiency for cloud service users.

Opinion of the board

Based on the insight into doctoral dissertation application, examining research topic and aim, hypotheses and research methods, literature and resources used throughout the doctoral thesis, as well as the doctoral dissertation itself, we may conclude that the research in question has been performed in a comprehensive and thorough manner.

Based on the above-mentioned, we conclude that the PhD dissertation is valuable to be defended. Therefore, we propose to the Department for Postgraduate Studies of the University Singidunum, Belgrade to approve the candidate *MOHAMED ABDUSALAM Y SALB* to defend PhD dissertation under the title: "Application of Hybrid Methods Combining Recurrent Neural Networks and Modified Metaheuristics for Time-Series Forecasting".

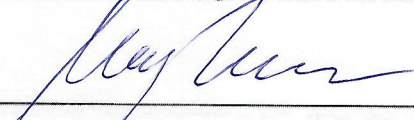
Belgrade, 24/10/2024

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