Technical Note

Not peer-reviewed version

Computational Intelligence Assisted Less-Expensive Privacy-Preserving Optimization in Audio-Video Content

Amir Parnianifard *

Posted Date: 17 April 2024

doi: 10.20944/preprints202404.0807.v1

Keywords: Computational Intelligence; Privacy-Preserving Optimization; Audio-Visual Content; Evolutionary Computation; Metamodel-Based Learning; Signal Watermarking

Technical Note

Computational Intelligence Assisted Less-Expensive Privacy-Preserving Optimization in Audio-Video Content

Amir Parnianifard

Glasgow College, University of Electronic Science and Technology of China, Chengdu, China; amir.p@uestc.edu.cn

Abstract: This research study focuses on addressing practical optimization challenges in audio-visual content using advanced computational intelligence methods, with a specific emphasis on privacy-preserving issues. The research will be presented as a proposal and can be conducted based on the provided ideas. Computational intelligence encompasses various approaches, including evolutionary algorithms, learning methods, fuzzy systems, and neural networks, which have become essential tools for tackling complex engineering optimization problems due to computational expenses, dimensional complexities, and interdisciplinary integration. The research objectives include a thorough investigation of optimization challenges in audio-visual content, the delineation of problem characteristics, and the development of relevant methodologies based on these specifications. The main goals of the study, titled "Advanced Computational Intelligence Assisted Less-Expensive Privacy-Preserving Optimization," encompass the development of a metamodel-based learning algorithm integrated with evolutionary computation for privacy-preserving optimization, less-expensive signal watermarking optimization using hybrid metamodeling and evolutionary algorithms, and a closed-loop robust intelligent PID control system applied in real-time dynamic signal watermarking. Additional objectives may be defined as the research progresses and further background review is conducted.

Keywords: computational intelligence; privacy-preserving optimization; audio-visual content; evolutionary computation; metamodel-based learning; signal watermarking

1. Brief Introduction

In this research study, the open practical optimization issues in audio-visual content will be studied and developed using advanced computational intelligence methods. Accordingly, the privacy-preserving issue will be considered as well through the main research objectives of the current study. In general, computational intelligence includes some main groups of approaches such as evolutionary algorithms, learning methods (metamodels), fuzzy systems, and neural networks. Addressing real-world engineering optimization challenges is often hindered by significant computational expenses, dimensional complexities, and the integration of multiple disciplines. Adding to these challenges, the presence of inherent uncertainties can further intensify the difficulties faced. Consequently, computational intelligence methods also referred to as metamodels or computationally efficient approximations of the actual costly functions, have emerged as robust approaches to mitigate or alleviate these challenges over the past thirty years. Researchers have employed sampling-based learning techniques, including Kriging (Gaussian process), radial basis functions, and polynomial regression models, to identify and approximate the problem characteristics. These approximation models not only "learn" the problem dynamics but also expedite the function evaluation process [1–4].

 doi:10.20944/preprints202404.0807.v1

2. Research Objectives

In this research study, our first step is to thoroughly investigate the real optimization challenges presented by audio-visual content. Subsequently, the primary characteristics of each problem are delineated, encompassing objective function(s), design variables, constraint functions, and uncertainty factors. Based on the specifications of each problem, the relevant methodology will be developed. It's worth noting that the specific optimization challenges in audio-visual content will be more precisely defined following an in-depth review of the study's background. This will include a comprehensive examination of existing literature pertinent to the current research area. Consequently, computational intelligence-based design optimization techniques will be developed and applied to address these practical optimization challenges in audio-visual content.

According to the main goal of the current study namely **"Computational Intelligence Assisted Less-Expensive Privacy-Preserving Optimization"**, three main research objectives (but not limited to) are considered through the current research work as follows:

1- Development of a Metamodel-Based Learning Algorithm Integrated Evolutionary Computation for Privacy-Preserving in Optimization.

2- Less-Expensive Signal Watermarking Optimization Using Hybrid Metamodeling and Evolutionary Algorithm.

3- Closed Loop Robust Intelligent PID Control System Applied in Real-Time Dynamic Signal Watermarking.

Note that these objectives are defined initially, however, more objectives will be defined according to progress over deep reviewing of the relevant background of the study.

3. Materials and Methods

In this research study to achieve the mentioned research objectives, the integration of three main methodologies is considered including metamodeling, metaheuristics, and robust design optimization.

3.1. Metamodelling

In our approach, we employ metamodels, which are particularly well-suited for black-box problems. These metamodels do not necessitate the identification of the system's internal structure or specific expressions. Instead, they analyze outputs based on a predetermined set of inputs, offering a more flexible and efficient way to approximate complex systems. Recent studies and literature have increasingly emphasized the advantages of utilizing metamodels in various engineering design applications, including audio-visual speech recognition. This growing preference for metamodels over alternative methods is primarily driven by the escalating complexity of real-world systems, which often require approximation techniques that are both accurate and cost-effective, as cited in [2,5–22]. Metamodeling techniques are intricately linked with the Design and Analysis of Computer Experiments (DACE). These techniques leverage a diverse set of statistical and mathematical methods to interpret and understand the relationships between parameters within the original model. Through this integrated approach, metamodels offer a robust and efficient means to tackle complex engineering optimization problems. A metamodel (also called surrogate model), in general, can be symbolized by the mathematical expression $\hat{Y} = f\widehat{(X,Z)}$ that it is replaced with the original functional of $Y = f(X,Z)$, where parameters X and Z denote the decision and uncertain (noise) variables in the model, respectively.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 April 2024 doi:10.20944/preprints202404.0807.v1

3.2. Evolutionary Algorithms

Optimization problems frequently encountered in various fields are often classified as NP-hard, making it quite challenging to implement exact solution methodologies. Due to these inherent complexities, engineers and researchers have increasingly turned to metaheuristic approaches. These methods offer the advantage of producing effective solutions within a reasonable computational timeframe, circumventing the difficulties associated with NP-hard problems. Metaheuristic algorithms can be broadly classified into two primary categories: local search methods and global search methods. Within the realm of local search methods, both taboo search and simulated annealing have gained significant recognition for their efficacy. Moreover, the use of tunneling algorithms has been shown to expedite the convergence of these methods. On the other hand, global methods encompass evolutionary algorithms and swarm-based techniques, which have become particularly prominent in the field of computational intelligence. Notable examples of these algorithms include the Genetic Algorithm (GA), Differential Evolution (DE), and Particle Swarm Optimization (PSO), as referenced in [23–25] In the context of computational intelligence, an evolutionary algorithm represents a specialized form of evolutionary computation, which operates on a population-based metaheuristic optimization framework. Drawing inspiration from the principles of biological evolution, these algorithms incorporate mechanisms such as reproduction, mutation, recombination, and selection. In this framework, candidate solutions to be optimal in an optimization problem can be likened to individuals within a population. The quality and effectiveness of these solutions are then evaluated and determined by a fitness function tailored to the specific optimization problem at hand.

3.3. Robust Design Optimization

Robust Design Optimization (RDO) is a methodology used in engineering to enhance the reliability and performance of products or systems by minimizing the effects of variability and uncertainty in decision variables. The RDO process begins with clearly defining the objective function, design variables, constraints, and uncertainty factors. Through the use of Design of Experiments (DOE) and metamodeling, surrogate models are developed to approximate system performance based on collected data. Optimization algorithms, such as metaheuristics or evolutionary algorithms, are then employed to find the optimal design that maximizes the objective function while adhering to constraints. This approach ensures that the designed products or systems are less sensitive to variations and uncertainties, leading to improved reliability, cost-efficiency, and enhanced performance across various engineering disciplines, including automotive, aerospace, mechanical, electrical, civil, and bioengineering [2,13,17,18].

Robust design optimization is an engineering methodology aimed at enhancing model performance by minimalizing the impact of variants, without necessarily excluding the underlying causes, which may be too challenging or costly to control. Robust simulation optimization focuses on efficiently solving simulation models with uncertain data. The primary objective of a robustness strategy is to determine the optimal settings for input factors that yield desirable output goals, even when faced with changes in uncertain parameters [26–28].

4. Proposed Approaches

Through this research study, firstly the real optimization problems in audio-visual content need to be investigated clearly. Accordingly, the main characteristics of each problem are defined including objective function(s), design variables, constraints functions, and uncertainty factors. Then, concerning each problem specification, the relevant methodology will be developed. Notably, the detailed problems for optimization in audio-video content will be defined after a more deep review of the background of the study including a study of the existing literature on the area of the current research. Accordingly, the application of computational intelligence-based design optimization will be developed and employed for such practical problems in audio-video content.

In the following we briefly explain the main ideas and approaches dealing with each research objective:

4.1. Proposed Methodology Regarding the First Research Objective

In recent years, there have been significant and rapid advancements in the field of evolutionary computation. A prevalent belief within this domain is that algorithm designers typically have access to the objective function of the optimization problem. This accessibility enables them to calculate the fitness values of individual solutions, which is in line with the fundamental principle of "survival of the fittest" as observed in natural selection. However, real-world applications often present unique challenges. In some cases, the objective function may be confidential or proprietary, thereby preventing the algorithm designer from directly obtaining the fitness values of the individuals being evaluated. This particular situation gives rise to a complex and significant challenge referred to as privacy-preserving optimization. In this context, the traditional assumption of having access to the objective function no longer holds true, necessitating the development of novel approaches and techniques to address this issue [29]. Addressing privacy-preserving optimization has emerged as a new and challenging frontier in the evolutionary computation community. While it's a relatively understudied area, it represents a significant and challenging research topic [30,31].

In this research study, we will extend a new algorithm for such a case when the value of the fitness function for each individual is private, so it can not be used directly in the optimization procedure. We will evaluate our proposed algorithm for real-world numerical examples in auidi0video content. The main idea is to use the rank instead of the exact magnitude of the fitness function. Figure 1 illustrates the schematic representation of the proposed privacy-preserving optimization in the current study through the first research objective.

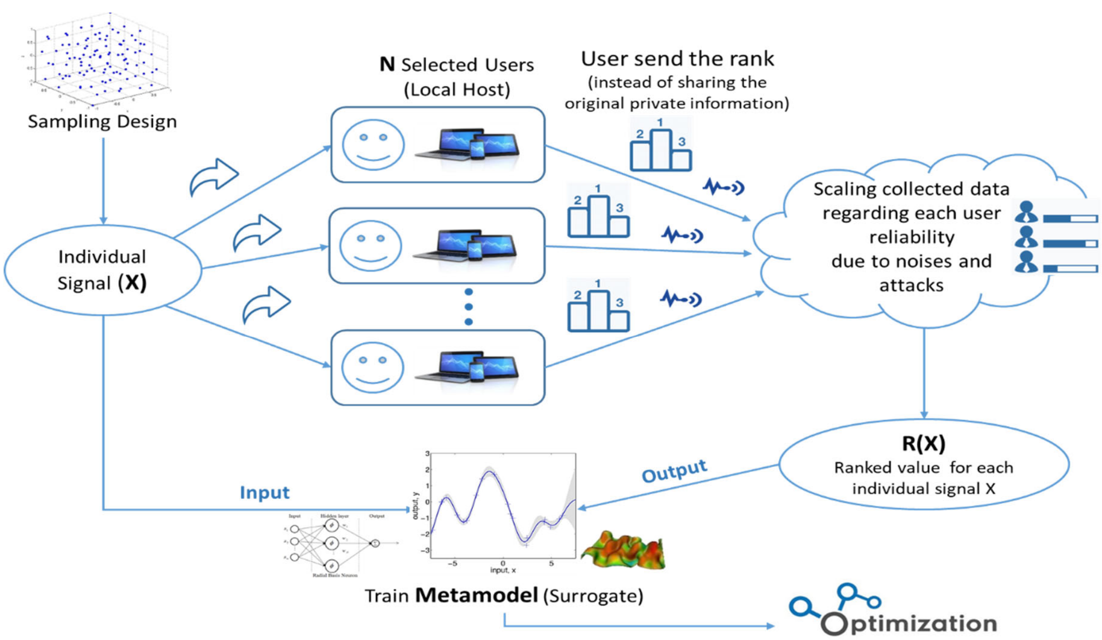

Figure 1. The schematic representation of proposed privacy-preserving optimization.

4.2. Proposed Methodology Regarding the Second Research Objective

Various studies have employed evolutionary algorithms to tackle signal watermarking, including image, audio, and video, as cited in [32]. A primary challenge in audio watermarking is determining the optimal value for the scaling factor. This value influences a trade-off between robustness and imperceptibility [33]. A higher scaling factor enhances the robustness of the embedded watermark but reduces the imperceptibility of the watermarked signal, and vice versa

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 April 2024 doi:10.20944/preprints202404.0807.v1

[34,35]. Audio watermarking serves as a high-security feature; unauthorized users lacking access to this information cannot detect any concealed data. The detection of the pseudo-noise sequence is pivotal for revealing hidden information in spread spectrum audio watermarking.

While heuristic techniques such as evolutionary algorithms can be utilized for the detection of pseudo-noise sequences, the substantial computational expenses associated with this method can make it less feasible for practical applications. One of the major challenges in employing evolutionary algorithms as an optimization tool is the evaluation of the fitness function. This evaluation can be particularly difficult to define accurately and can also be computationally intensive, thereby limiting the efficiency and scalability of the approach. In our proposed methodology, which aims to enhance privacy and reduce computational costs, we first develop and train a metamodel using a restricted dataset obtained from users. This metamodel serves as an approximation model and is subsequently employed to predict the fitness function during the optimization process. By doing so, we eliminate the necessity of using the original user data, thus addressing privacy concerns while also mitigating the computational expenses associated with the traditional approach.

4.3. Proposed Methodology Regarding the Third Research Objective

Through the third research objective in the current study, we are going to expand the application of closed-loop control systems in real-time and time-based optimization problems in audio-video content. Figure 2 schematically shows the general application of the PID closed-loop controller in real-time privacy-preserving control (e.g., real-time signal watermarking). Among developing the third research objective, the details of control system application in time-based audio-video content will be studied as well as employing a few real-world problems mostly over time-based privacy-preserving and signal-processing accordingly.

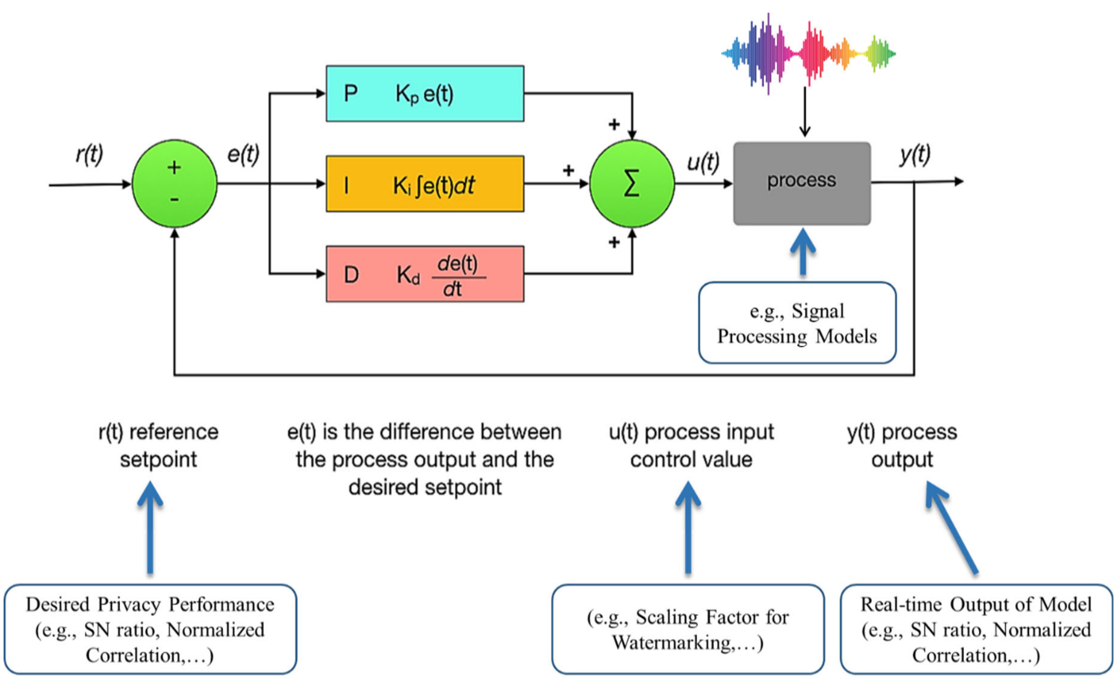

Figure 2. The proposed application of PID control system in time-based privacy-preserving content.

5. Timeline

For the current study, the primary anticipated deliverables include research publications in reputable high-quality journals, presentations at relevant conferences, and comprehensive progress reports corresponding to each of the specified research objectives. It should be noted that the objectives outlined are intended to be achieved within a one-year timeframe. As the research progresses and a deeper review of the relevant background literature is conducted, new objectives for the second year will be defined and integrated into the research framework. Figure 3 provides a detailed timeline and schedule outlining the key stages and milestones, particularly with respect to the research objectives of the current study, to ensure systematic and timely progress towards the project's goals.

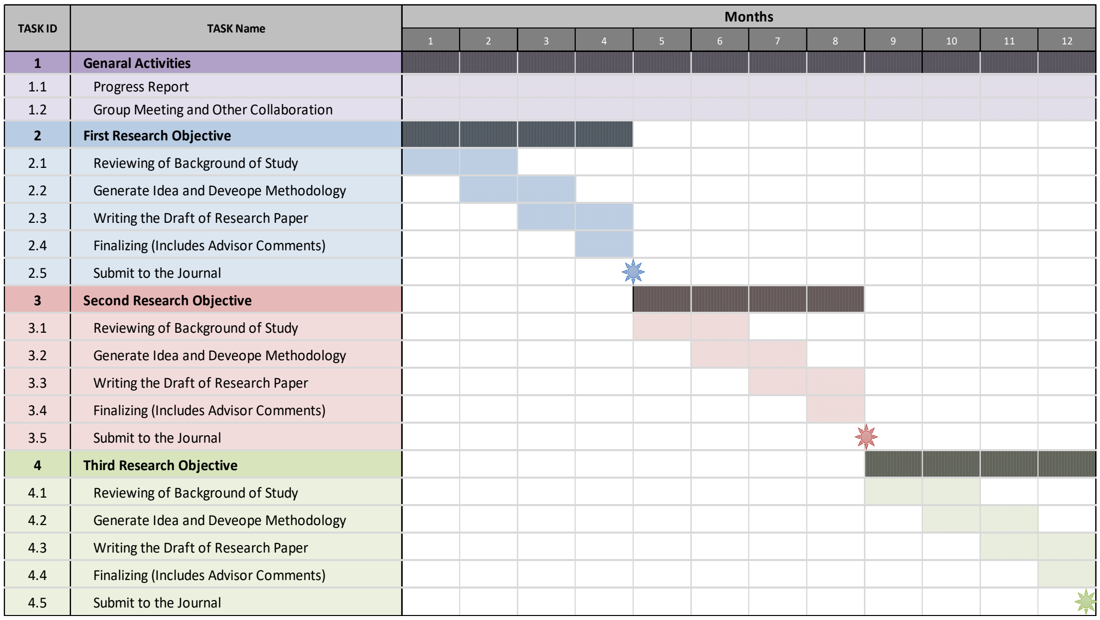

Figure 3. The Gantt chart of the current study for one year to reach three considered research objectives.

References

1. B. Ali Asghar, Computational Intelligence and Its Applications in Uncertainty-Based Design Optimization, in Bridge Optimization-Inspection and Condition Monitoring, IntechOpen, 2019.
2. A. Parnianifard, A. Azfanizam, M. Ariffin, M. Ismail, and N. Ebrahim, *Recent developments in metamodel based robust black-box simulation optimization: An overview*, Decision Science Letters, 8, (1), pp. 17–44, 2019.
3. A. Parnianifard, A. S. Azfanizam, M. K. A. Ariffin, and M. I. S. Ismail, *Trade-off in robustness, cost and performance by a multi-objective robust production optimization method*, International Journal of Industrial Engineering Computations, 10, (1), pp. 133–148, 2019.
4. A. Parnianifard, A. S. Azfanizam, M. K. A. Ariffin, and M. I. S. Ismail, *An overview on robust design hybrid metamodeling : Advanced methodology in process optimization under uncertainty*, International Journal of Industrial Engineering Computations, 9, (1), pp. 1–32, 2018.
5. A. Parnianifard and A. S. Azfanizam, *Metamodel-based robust simulation-optimization assisted optimal design of multiloop integer and fractional-order PID controller*, International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, 33, (1), p. e2679, 2020.
6. A. Parnianifard, A. S. Azfanizam, M. K. A. Ariffin, and M. I. S. Ismail, *Kriging-Assisted Robust Black-Box Simulation Optimization in Direct Speed Control of DC Motor Under Uncertainty*, IEEE Transactions on Magnetics, 54, (7), pp. 1–10, 2018.
7. A. Parnianifard, A. Azfanizam, M. Ariffin, M. Ismail, and N. Ebrahim, *Recent developments in metamodel based robust black-box simulation optimization: An overview*, Decision Science Letters, 8, (1), pp. 17–44, 2019.
8. A. Parnianifard and A. S. Azfanizam, *Metamodel-based robust simulation-optimization assisted optimal design of multiloop integer and fractional-order PID controller*, International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, 33, (1), p. e2679, 2020.
9. A. Parnianifard, S. Jearavongtakul, P. Sasithong, and N. Sinpan, *Digital-Twins towards Cyber-Physical Systems : A Brief Survey*, Engineering Journal, 26, (9), pp. 47–61, 2022.
10. A. Parnianifard, R. Chancharoen, G. Phanomchoeng, and L. Wuttisittikulkij, A New Approach for Low-Dimensional Constrained Engineering Design Optimization Using Design and Analysis of Simulation Experiments, International Journal of Computational Intelligence Systems, 13, (1), pp. 1663–1678, 2020.

11. A. Parnianifard, A. Zemouche, M. A. Imran, and L. Wuttisittikulkij, Robust simulation-optimization of dynamic-stochastic production/inventory control system under uncertainty using computational intelligence, Uncertain Supply Chain Management, 8, (4), pp. 633–648, 2020.
12. A. Parnianifard, M. Fakhfakh, M. Kotti, A. Zemouche, and L. Wuttisittikulkij, Robust tuning and sensitivity analysis of stochastic integer and fractional-order PID control systems : application of surrogate-based robust simulation-optimization, International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, 34, (2), p. e2835, 2020.
13. A. Parnianifard, S. Chaudhary, S. Mumtaz, L. Wuttisittikulkij, and M. A. Imran, *Expedited surrogate-based quantification of engineering tolerances using a modified polynomial regression*, Structural and Multidisciplinary Optimization, 66, (3), p. 61, 2023.
14. A. Parnianifard, S. Mumtaz, S. Chaudhary, M. A. Imran, and L. Wuttisittikulkij, *A data driven approach in less expensive robust transmitting coverage and power optimization*, Scientific Reports, 12, p. 17725, 2022.
15. A. Parnianifard, V. Rezaie, S. Chaudhary, M. A. Imran, and L. Wuttisittikulkij, New Adaptive Surrogate-Based Approach Combined Swarm Optimizer Assisted Less Tuning Cost of Dynamic Production-Inventory Control System, IEEE Access, 9, pp. 144054–144066, 2021.
16. A. Parnianifard, A. Zemouche, R. Chancharoen, M. A. Imran, and L. Wuttisittikulkij, Robust optimal design of FOPID controller for five bar linkage robot in a Cyber-Physical System: A new simulation-optimization approach, PLOS ONE, 15, (11), p. e0242613, Nov. 2020.
17. A. Parnianifard, A. S. Azfanizam, M. K. A. Ariffin, and M. I. S. Ismail, Comparative study of metamodeling and sampling design for expensive and semi-expensive simulation models under uncertainty, SIMULATION, 96, (1), pp. 89–110, May 2019.
18. A. Parnianifard, A. S. Azfanizam, M. K. A. Ariffin, and M. I. S. Ismail, *Crossing weighted uncertainty scenarios assisted distribution-free metamodel-based robust simulation optimization*, Engineering with Computers, 36, (1), pp. 139–150, 2019.
19. A. Parnianifard, A. S. Azfanizam, M. K. A. Ariffin, and M. I. S. Ismail, Design and Analysis of Computer Experiments Using Polynomial Regression and Latin Hypercube Sampling in Optimal Design of PID Controller, Journal of Applied Research on Industrial Engineering, 5, (2), pp. 156–168, Aug. 2018.
20. A. Parnianifard, A. S. Azfanizam, M. K. A. Ariffin, and M. I. S. Ismail, *Kriging-Assisted Robust Black-Box Simulation Optimization in Direct Speed Control of DC Motor Under Uncertainty*, IEEE Transactions on Magnetics, 54, (7), pp. 1–10, 2018.
21. A. Parnianifard, A. S. Azfanizam, M. K. Ariffin, M. I. Ismail, M. R. Maghami, and C. Gomes, Kriging and Latin Hypercube Sampling Assisted Simulation Optimization in Optimal Design of PID Controller for Speed Control of DC Motor, Journal of Computational and Theoretical Nanoscience, 15, (5), pp. 1471–1479, 2018.
22. A. Parnianifard et al., Hybrid Metamodeling / Metaheuristic Assisted Multi-Transmitters Placement Planning, Computers, Materials & Continua, 68, (1), pp. 569–587, 2021.
23. R. G. Regis, Particle swarm with radial basis function surrogates for expensive black-box optimization, Journal of Computational Science, 5, (1), pp. 12–23, 2014.
24. A. Parnianifard, A. Zemouche, R. Chancharoen, M. A. Imran, and L. Wuttisittikulkij, Robust optimal design of FOPID controller for five bar linkage robot in a Cyber-Physical System: A new simulation-optimization approach, PLOS ONE, 15, (11), p. e0242613, Nov. 2020.
25. A. Parnianifard et al., Hybrid Metamodeling / Metaheuristic Assisted Multi-Transmitters Placement Planning, Computers, Materials & Continua, 68, (1), pp. 569–587, 2021.
26. G. J. Park, T. H. Lee, K. H. Lee, and K. H. Hwang, *Robust Design : An Overview*, AIAA Journal, 44, (1), pp. 181–191, 2006.
27. T. Chatterjee, S. Chakraborty, and R. Chowdhury, *A Critical Review of Surrogate Assisted Robust Design Optimization*, Archives of Computational Methods in Engineering, 26, (1), pp. 245–274, 2019.
28. A. J. Keane and I. I. Voutchkov, *Robust design optimization using surrogate models*, Journal of Computational Design and Engineering, 7, (1), pp. 44–55, 2020.
29. Z. H. Zhan, S. H. Wu, and J. Zhang, A New Evolutionary Computation Framework for Privacy-Preserving Optimization, in 2021 13th International Conference on Advanced Computational Intelligence (ICACI) , IEEE., 2021, May, pp. 220–226.
30. H. Nakayama, M. Arakawa, and R. Sasaki, *A computational intelligence approach to optimization with unknown objective functions*, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 2130, pp. 73–80, 2001.
31. H. Nakayama, M. Arakawa, and R. Sasaki, *Simulation-Based Optimization Using Computational Intelligence*, Optimization and Engineering, 3, (2), pp. 201–214, 2002.
32. R. M. Thanki, Advanced Techniques for Audio Watermarking. 2020.
33. Z. Su, G. Zhang, F. Yue, L. Chang, J. Jiang, and X. Yao, *SNR-constrained heuristics for optimizing the scaling parameter of robust audio watermarking*, IEEE Transactions on Multimedia, 20, (10), pp. 2631–2644, 2018.

doi:10.20944/preprints202404.0807.v1

34. S.-T. Chen and H.-N. Huang, *Optimization-based audio watermarking with integrated quantization embedding*, Multimedia Tools and Applications, 75, (8), pp. 4735–4751, 2016.
35. M. Ketcham and S. Vongpradhip, *Intelligent audio watermarking using genetic algorithm in DWT domain*, International Journal Of Intelligent Technology, 2, (2), pp. 135–140, 2007.