DCE23 5th DOCTORAL CONGRESS IN ENGINEERING

Book of Abstracts

DCE23 - Symposium on Electrical and Computer Engineering

U.PORTO
FEUP FACULDADE DE ENGENHARIA
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DCE 23 5th DOCTORAL CONGRESS IN ENGINEERING

Book of Abstracts

of the

Symposium on Electrical and Computer Engineering

Editors:
Luís Almeida, Nuno Fidalgo, Gowhar Javanmardi, Tiago Gonçalves

Porto
June 2023

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This volume contains the peer reviewed and accepted abstracts, presented at the Symposium on Electrical and Computer Engineering, of the 5th Doctoral Congress in Engineering – DCE23, held at FEUP-U.Porto, Porto, Portugal, between June 15th and 16th, 2023.

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Welcome

Welcome to the Symposium on Electrical and Computer Engineering at the Doctoral Congress in Engineering (DCE) 2023! This Book of Abstracts contains fourteen abstracts submitted and accepted in this symposium, associated with doctoral projects that cover a wide breadth of research in the vibrant field of Electrical and Computer Engineering (ECE). Ten abstracts refer to oral communications presented in two sessions, and four refer to posters presented in the poster session with a pitch delivered in the second oral session. The abstracts encapsulate cutting-edge research, showcasing diverse areas that extend from management of renewable energy production to intersections management, computer networks, health support systems, application and operation of machine learning methods, and more.

This Symposium also includes a keynote speech by Luís Sarmento from *Inductiva Research Labs* entitled *The Elephants in the Room: Hardware in AI*. This speech is followed by a panel consisting of researchers that use AI methods in diverse areas of Electrical and Computer Engineering. This panel will discuss which AI methods are more common in ECE, whether there is a convergence of such methods, the execution requirements of these methods to run effectively, whether these methods will become deeply embedded and whether conventional methods will be replaced by AI methods. The other panel is composed of female professionals from the ECE domain and will discuss the persisting gender imbalance in Electrical and Computer Engineering. In particular, the panel will start from the current imbalance situation and discuss what would be a desired gender balance and which mechanisms can help achieve that. Finally, we also offer two workshops open to all congress participants, delivered by students of the Doctoral Program in Electrical and Computer Engineering (PDEEC) of the Faculty of Engineering of the University of Porto (FEUP), namely *Introduction to Git: Mastering Version Control* by Diogo Cordeiro and *Spiking Neural Networks: Fundamentals and Applications* by João Nunes. These activities together with the oral communications and posters complemented by the social activities offered by the congress are excellent opportunities to connect, engage in stimulating discussions, build lasting connections with colleagues, and last but not least, foster motivation for successfully advancing the respective doctoral projects. In the end, two awards will be given out, the Best Abstract Award and the Best Presentation Award, which recognize the effort the authors have put into this participation.

We end this welcome message with a strong word of appreciation to all that submitted their work to this Symposium, to the organisers of the workshops, to the keynote speaker and members of the panels, to the organisers of the overarching DCE congress and finally to all that registered for participation. Whether you are an expert, researcher, or enthusiast, we hope this Book of Abstracts inspires your passion for research and that this Congress and particularly this Symposium will provide you with an enlightening, enriching, and inspirational experience.

See you at DCE 2023!

Porto, June 2023

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Gowhar Javanmardi

José Nuno Moura Marques Fidalgo

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Symposium Programme | June 15th

Global Activities | 08h00-14h00

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Posters

- **Context-Aware Reinforcement Learning for Supporting WiFi Connectivity for Vehicles**
  Mushahid Hussain, Felipe França, Ana Aguiar
- **Towards an End-to-End Energy Model for Virtualized RANs**
  Sofia Martins, Ana Aguiar, Peter Steenkiste
- **Man-Machine Symbiosis: Towards an implicit and affective relationship between man and machine**
  Vitor Minhoto, João Paulo Silva Cunha
- **Towards reducing resource consumption of ML and DL algorithms in Embedded Systems**
  Asulba Barikisu, Luís Almeida, Pedro Souto

Workshops

- **Introduction to Git: Mastering Version Control**
  Diogo Peralta Cordeiro

- **Spiking Neural Networks: Fundamentals and Applications**
  João Diogo Fernandes Freitas Nunes

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- **Machine Learning applied to adaptive optics deep space imaging**
  Francisco S.F. Ribeiro, Paulo J.V. Garcia, Miguel Silva, Richard Davies, Jaime S. Cardoso
- **Complex Intersections with a Dedicated Road Lane per Crossing Direction**
  Radha Reddy, Luís Almeida, Pedro Santos, Eduardo Tovar
- **In-bed action recognition for clinical diagnosis support: A two-stage, 3D motion capture and skeleton action recognition based approach**
  Tamás Karácsony, João Paulo Silva Cunha
- **Airborne Communications: an obstacle-aware positioning algorithm**
  Kamran Shafafi, Manuel Ricardo, Rui Campos
- **Performance Measurements of Broadband Network Gateways**
  Rubens Figueiredo, Andreas Kassler, Holger Karl
- **Wireless Body Area Network Architecture with Precise Synchronisation Services for Advanced Electro-Optical Neuromodulation Devices**
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Panel members:

- Ana Filipa Sequeira | INESC TEC
- Paula Rocha Malonek | FEUP
- Teresa Andrade | FEUP
- Teresa Ponce Leão | LNEG

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Chaired by Nuno Fidalgo
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  André Saraiva, Jelena Devenson, Vasile-Dan Sas, Attila Fejes
- **Wavelet Scattering Transform for Enhanced ECG Feature Extraction and Analysis**
  Pedro Henrique Borghi, João Paulo Teixeira, Diamantino Rui Freitas
- **Comparing Morphological Traits of Fish Images to Determine Isometric or Allometric Growth**
  Luiz Claudio Navarro, Ana Azevedo, Aníbal Matos, Anderson Rocha, Rodrigo Ozório
- **Bess Operation Assessment Regarding the Rise in the Energy Prices**
  Piedy Agamez-Arias, Vladimiro Miranda

Session 2: Poster Pitches | 10h00-10h30
Chaired by Nuno Fidalgo
Poster Pitches:

- **Context-Aware Reinforcement Learning for Supporting WiFi Connectivity for Vehicles**
  Mushahid Hussain, Felipe França, Ana Aguiar
- **Towards an End-to-End Energy Model for Virtualized RANs**
  Sofia Martins, Ana Aguiar, Peter Steenkiste
- **Man-Machine Symbiosis: Towards an implicit and affective relationship between man and machine**
  Vitor Minhoto, João Paulo Silva Cunha
- **Towards reducing resource consumption of ML and DL algorithms in Embedded Systems**
  Asulba Barikisu, Luís Almeida, Pedro Souto

Coffee-Break | 10h30-11h00

Keynote Talk | 11h00-12h00
Chaired by Nuno Fidalgo
Invited Talk: **The Elephants in the Room: Hardware in AI** by Luís Sarmento

Panel 2: Artificial Intelligence in Electrical and Computer Engineering | 12h00-13h00
Moderated by Nuno Fidalgo
Panel members:

- Jaime S. Cardoso | FEUP
- Luís Paulo Reis | FEUP
- Ricardo Bessa | INESC TEC
- Vítor Grade Tavares | FEUP

Symposium Keynote Speaker

Speaker: Luís Sarmento (PhD, Co-founder & CEO of Inductiva Research Labs)

Keynote Talk: The Elephants in the Room: Hardware in AI

Luís Sarmento is a researcher in Artificial Intelligence (AI), focusing mostly on Machine Learning (ML). He holds a degree in Electrical Engineering (1999), an MSc in Artificial Intelligence (2004), and a PhD in Informatics, all from the University of Porto (2010). He has more than 15 years of experience leading research teams both in academic (University of Porto, National Foundation for Scientific Computing, Portugal) and industrial settings (Portugal Telecom, Amazon, Google), in the fields of Search Engines, Recommender Systems and Dialog Systems. In 2021, Luís co-founded Inductiva Research Labs, a research-driven start-up company focused on delivering Artificial Intelligence solutions to problems in the fields of engineering and science. At Inductiva, Luís is working on developing a team of talented Scientific Machine Learning researchers and engineers capable of achieving breakthroughs in fundamental sciences.

Oral Communications to be presented in the Symposium

Machine Learning applied to adaptive optics deep space imaging

Francisco S.F. Ribeiro[1], Paulo J.V. Garcia[2], Miguel Silva[3], Richard Davies[4], Jaime S. Cardoso[5]

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Abstract

Context: Point source identification and measurement (flux and position) find many applications in computer vision, such as deep space imaging, microscopy, lithography, ophthalmology, and others. In the context of adaptive optics, this type of image exhibits significant spatial and temporal variability in the point spread function, which is challenging for classical approaches. These rely on point spread function fitting to detect and compute the flux and position. Machine learning techniques are extremely popular due to their precision, reliability, and computational cost, and they outperform their counterparts, especially on datasets with significant noise and variance. This is the particular context of adaptive optics.

Aims: The goal is to develop an automatic point source-detector that provides reliable measurement of the fluxes and position of different stars within a group.

Methods: We will use simulated adaptive optics images to train the network and to quantify: a) the source detection efficiency; b) the accuracy of the measurements of the flux and position in machine learning-driven algorithms compared to classical DAOPHOT-like approaches. We will then apply the algorithm to real data.

Results: We show that the algorithm has a significantly higher source detection efficiency than classical approaches. It also shows better performance in flux measurements. We discuss the details required for accurate measurements.

Complex Intersections with a Dedicated Road Lane per Crossing Direction

Radha Reddy[1,2,3], Luís Almeida[1,3], Pedro Santos[1,2,3], Eduardo Tovar[1,2]

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Abstract

Complex intersections are often busier with multiple road lanes. These road lanes can be either dedicated to each crossing direction, i.e., one road lane per left, straight, and right-crossing, or shared between multiple crossing directions. Numerous intersection management (IM) strategies have been presented to manage continuously growing traffic over the years (Namazi et al., 2019). Figure 1a presents a real-world complex intersection with multiple road lanes as a motivational intersection. Relying on this, we designed intersections with a separate road lane per crossing direction. In these kinds of intersections, right-crossing vehicles have the right-of-way. Therefore, only the straight- and left-crossing vehicle lanes fall under traffic signal control. One way of serving such intersections is permitting vehicles from one roadway at a time, then shifting to the next roadway. The conventional Round-Robin (RR) IM approach is an example of this kind, shown in Figure 1b.

In contrast, the synchronous intersection management protocol (SIMP) synchronizes vehicle intersection access from multiple road lanes but one vehicle from each non-conflicting road lane (Reddy et al. 2019, 2020). This abstract presents an extension to the SIMP for serving four-way three-lane intersections. SIMP can choose the non-conflicting road lanes associated with the straight-crossing North and South lanes, as shown in Figure 1c. The selection of non-conflicting road lanes is based on the presence of the vehicle at the intersection entrance identified using the induction loop detectors placed in various places around intersections.

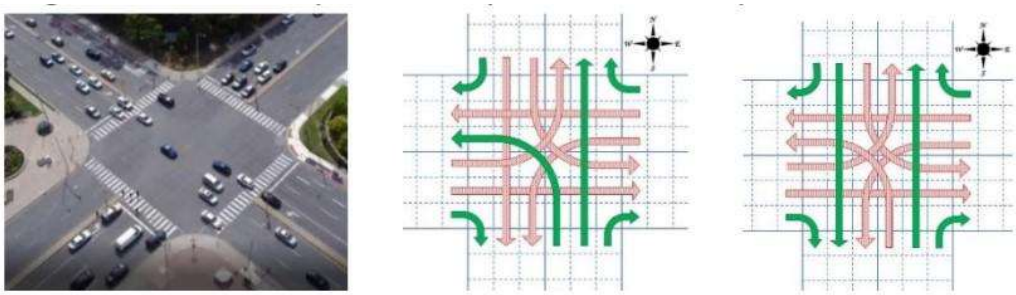

Figure 1: a). Real-world road intersection, b). vehicles serving from one road at a time, and c). vehicles serving from multiple road lanes.

We use the SUMO simulator to build the road network mentioned earlier and compare RR and SIMP IM approaches (Lopez et al., 2018). The traffic is generated for various traffic arrival rates using a Poisson distribution and randomly distributed equally to the three crossing directions at 30km/h speed without U-turns to the source. For the other parameters, associated values, and fuel consumption model, see Reddy et al. (2019, 2020).

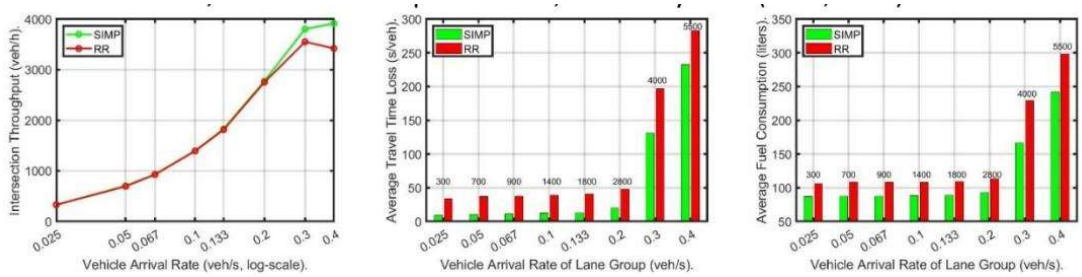

Figure 2: a). Intersection throughput, b). average travel time loss, and c). average fuel consumption.

Figure 2a, 2b, and 2c show the comparing IM approaches performance respecting the intersection throughput (veh/h) and average results of travel time loss (s/veh) and fuel consumption (liters) for various arrival rates and vehicle count. The throughput results indicate that the SIMP serves the highest number of vehicles due to the synchronous way of serving vehicles and saturates at 0.4veh/s against the conventional RR, which saturate at 0.3veh/s. The travel time loss combines the waiting time at intersections and the time lost due to speed deviations like acceleration/deceleration for safe driving between consecutive vehicles. The travel time loss results show that the SIMP is the best approach with the lowest travel time loss values against RR. The fuel consumption results also show that similar trends correlate with the travel time results.

Acknowledgments

This work was supported by FCT/MCTES (Portuguese Foundation for Science and Technology) under grant UIDP/UIDB/04234/2020 (CISTER unit); by FCT through the European Social Fund (ESF) and the Regional Operational Programme NORTE2020, under grants 2021.05004.BD, POCI-01-0247-FEDER-045912 (FLOYD) and NORTE-01-0145-FEDER-000062 (RETINA); and by FCT and EU ECSEL JU within ECSEL/0010/2019 - JU grant nr. 876019 (ADACORSA) - The JU receives support from the European Union's Horizon 2020 research and innovation programme and Germany, Netherlands, Austria, France, Sweden, Cyprus, Greece, Lithuania, Portugal, Italy, Finland, Turkey (Disclaimer: This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains).

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In-bed action recognition for clinical diagnosis support: A two-stage, 3D motion capture and skeleton action recognition based approach

Tamás Karácsony[1,2,3], João Paulo Silva Cunha[1,2]

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Abstract

Many clinical scenarios involve in-bed monitoring both at the hospital or even at home giving in-bed action recognition technology a relevant position when we aim at behavior/motion capture monitoring. A wide range of potential clinical applications involve from intensive care and neuro-critical infirmary to sleep monitoring at home. One such relevant application is the epileptic seizure motion quantification for diagnosis support, in the neurology area, that is known to be a highly demanding environment to perform motion quantification for clinical support [1]. Although promising, action recognition in such clinical environments pose several challenges that need to be tackled in order to realize the full potential of this technology for routine clinical usage in the future.

Epileptic seizure semiology (the study of clinical signs during seizures to support diagnosis and therapeutic decisions) is currently performed through video monitoring data. There are other approaches utilizing techniques from classical computer vision, image or video classification, keypoint or keypoint stream classification, however only a few action recognition approaches exist [2, 3]. Most of these are end-to-end approaches. However, there is a need for quantification, and explainability of the classification to identify the movements contributing the most to the classification of the seizure, both from the clinical and technical perspective. To address the challenges of in-bed monitoring and action recognition systems, our group is developing approaches such as BlanketGen [4], to address the challenge of blanket occlusion present in these scenarios. To evaluate the improvements of approaches utilizing BlanketGen and other systems an action recognition dataset was developed of these scenarios dubbed as BlanketSet [5].

In order to recognize actions performed in bed, a two-step process is being developed. The proposed first stage of our approach extracts 3D motion capture (MoCap) data to track the full body movements of a person in the bed. Then the second stage uses this for skeleton action recognition to identify the specific actions that are being performed by the person in bed.

During the development we have identified the need for better quality data to improve the accuracy and reliability of our approach. To address this need, we have initiated the recording of a new 4K-RGB-D dataset of epileptic seizures and a Movement of Interest (MOI) simulation dataset, building on top of our previously developed collaborative development framework with our clinical partners [6]. This framework allows us to collect data in a real-world environment and to collaborate with clinicians to ensure that the data is collected in a way that is relevant to the clinical needs. This better quality data, with higher resolution is required for the quantification of full body movements, especially it is vital to track the hands and face. With this 4K resolution, the hands and face are still represented with a decent number of pixels, - on the scale of 150x150 for hands and 300x300 for face, from a viewpoint of a common clinical monitoring perspective, this is naturally 4 times the pixels compared to 1080p videos from the same viewpoint.

The expected results of using 3D MoCap for action recognition on 4K-RGB-D videos are that it will be able to quantify not just the large movements, but the smaller details of the scene, which can contribute to a better action recognition approach. It can also contribute to epileptic seizure classification with greater detail and explainability. Currently the data acquisition is ongoing, and promising initial MoCap results have been obtained on these 4K videos. Now, a temporo-spatially

stable 3D MoCap system is being developed, and it is expected to have a prototype system available soon.

The future work for this project includes testing the system on a new dataset that is being acquired and to improve the accuracy of the MoCap system and making it more robust to noise. Moreover, explore the explainability of the approach, as it allows users, clinicians to understand how the system is making its decisions, where the proposed 2-stage approach opens up the opportunity to provide quantitative explanations of the action classification based on the contributing movements.

We believe that our approach has several advantages over other approaches developed in scope of epileptic seizure classification for clinical in bed action recognition. First, our approach is aiming to capture the smaller details of the scene, which can be important for accurate action recognition. Second, our approach aims to provide explainability, which is cruicial for clinical diagnosis support applications where it is important to understand how the system is making its decisions.

In conclusion, the proposed 2-stage concept is a promising approach that has the potential to improve the accuracy and explainability of action recognition systems utilized for in-bed action recognition based clinical diagnosis support, by providing the quantified and interpretable latent space of 3D MoCap for video based action classification.

Acknowledgements

This work was partially funded by Fundação para a Ciência e a Tecnologia under the scope of the CMU Portugal program (Ref PRT/BD/152202/2021). We thank members of the Epilepsy Center, Department of Neurology, University of Munich, Munich, Germany for sharing their time and expertise to improve this work, namely Nicholas Fearns, Dr. Anna Mira Loesch Biffar, PD Dr. Dr. Christian Vollmar, Prof. Dr. med. Jan Rémi, Prof. Dr. Soheyl Noachtar.

We thank members of the Neurophysiology Unit, Neurology Department, Centro Hospitalar Universitário de São João, E.P.E., Porto, Portugal, for sharing their time and expertise to improve this work, namely Dr. Ricardo Rego.

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Airborne Communications: an obstacle-aware positioning algorithm

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Abstract

In natural and man-made disaster scenarios, such as wildfires, earthquakes, floods, and cyber and terrorist attacks, communications infrastructures may be- come unavailable. As part of the envisioned Next-Generation-Networks (NGN), aerial networks formed by Unmanned Aerial Vehicles (UAV) are emerging as a solution to provide on-demand and cost-effective wireless connectivity in these scenarios. However, there are still challenges to overcome, such as the issue of Line-of-Sight (LoS) availability at high frequencies, which can easily be obstructed by obstacles. The solution may lie in positioning UAVs to compensate for the loss of LoS, a hurdle yet to be fully addressed.

State of the art solutions can be classified into three categories: 1) UAV positioning assuming no obstacles, 2) Losing LoS due to dynamic obstacles in stationary 5G Base Stations (BSs), and 3) Using a 3D environment map to provide LoS by building reflection. While the first category focuses on optimizing the positions of UAVs, it assumes that there are no obstacles in the environment, which is not always the case in practical scenarios [1]. In the second category, the proposed solutions address the probability of users being blocked, but they only consider stationary 5G BSs, which limits their applicability in dynamic environments [2]. Finally, the third category proposes solutions that use a 3D map to provide LoS by building reflection. However, this approach is limited by the quality and accuracy of the map, which may not be available or up-to-date in all scenarios [3].

The main contribution of the paper is an obstacle-aware positioning algorithm for UAV-based networks aimed at autonomously determining the optimal position of UAVs to ensure LoS links with user equipment (UEs) in environments that are not obstacle-free. The goal is to ensure high-capacity links between the UAVs and UEs while accommodating the traffic demand of UEs. The algorithm takes into account several input parameters including signal-to-noise ratio, theoretical data rates of IEEE 802.11ac MCS indexes, transmission power, obstacle dimensions, and LoS restrictions.

To illustrate the execution of the algorithm we consider the example scenario depicted in Figure 1. The scenario comprises one UAV functioning as a Flying Access Point (FAP), two UEs on the ground, and a building positioned between the UEs as an obstacle. This scenario was simulated in ns-3 using the IEEE 802.11ac standard, with one spatial stream, an 800 ns Guard Interval (GI), and a 160MHz channel bandwidth (channel 50 at 5250 MHz). For the UE1, we considered a traffic demand of 702 Mbit/s, associated with the IEEE 802.11ac MCS index 8, while for the UE2, we considered a traffic demand of 234 Mbit/s, associated with the IEEE 802.11ac MCS index 3.

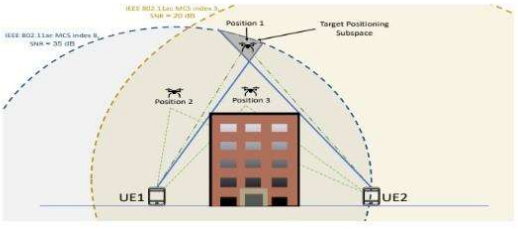

Figure 1: Target positioning algorithm scenario.

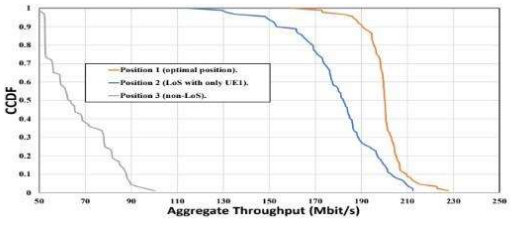

Figure 2: Aggregate throughput on UAV for three positions.

The algorithm's performance was evaluated using the aggregate throughput metric, which measures the average number of bits received per second by the UAV. We evaluated various UAV positions within the venue, including the optimal position (position 1), which was determined using the proposed algorithm, as well as position 2 and position 3, as shown in Figure 1. These positions were evaluated to demonstrate the benefits of using the proposed positioning algorithm. The traffic generated was UDP, utilizing a constant packet size of 1024 bytes. The simulation results shown in the plot of Figure 2 shows that in position 1 (selected by the proposed algorithm) the UAV has LoS with all UEs, while in position 2 there is LoS with only one UE and in position 3, there is no LoS with any UE. Notably, the results demonstrate gains of up to 200% in aggregate throughput when comparing the coordinates in non-LoS to the optimal position achieved by the proposed algorithm. As future work, we intend to analyze the algorithm's performance in more complex scenarios with more evaluation metrics such as delay and Packet Loss Ratio (PLR) and investigate the possibility of incorporating machine learning techniques to enhance the algorithm's efficiency and accuracy.

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Performance Measurements of Broadband Network Gateways

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Abstract

Broadband network access is typically managed by Broadband Network Gateways (BNGs), which implement complex services including authentication, authorization, and accounting (AAA), packet routing and forwarding, and Quality of Service (QoS) enforcement. QoS enforcement is especially complex to implement due to different subscriber tariffs, which require different traffic shaping, policing, and queue management policies to be supported in parallel at high fidelity. The recent network softwarization trend allows BNG functionality to be implemented as a Virtual Network Function (VNF). This enables flexible deployment strategies on commodity hardware, significantly reducing capital expenditure (CAPEX). However, the complex packet processing inside the BNG data plane makes it difficult to provide low and predictable latency at low loss at the scale required by access network subscribers. With the recent emergence of new, programmable, protocol-independent packet processing hardware targets (such as Field-Programmable Gate Arrays (FPGAs) or programmable ASICs), accelerating the BNG data plane on re-programmable hardware becomes feasible. But the vast range of deployment options makes it difficult to choose the programmable targets best suited for a particular key performance indicator.

The architecture and services of the BNG are described in several technical reports of the Broadband Forum. The functional split between control and user planes of the BNG was defined by the TR-459 [1], additionally describing the interfaces between these two components. The in-depth description of the different services is found in the TR-178 [2]. The design of BNG functionality as a VNF has been as well the target of academic studies. In Kundel et al. [3], the BNG was implemented in P4-enabled hardware targets and shows the achievable performance for the different targets. Since P4 is not designed to support packet queueing and scheduling, FPGAs are used to realize QoS functionality. Mejia and Rothenberg [4] proposes a P4-based BNG, using the MACSAD as the execution environment. The design of QoS functionality as a VNF, in particular packet scheduling, has been studied as well. Fejes et al. [5] proposes a system capable of describing hierarchical scheduling policies without needing to maintain a large set of queues. Xi et al. [6] proposes the offload of the Linux hierarchical token bucket (HTB) to Netronome SmartNIC. In this work, we measure and compare the performance of the same functionality based on different implementations, to characterize the tradeoffs between performance and flexibility.

To gain more insights into the different performance aspects of accelerating BNG packet processing functions, we perform a controlled benchmark study on the BNG use case on two targets. In particular, we first deploy a software version of BNG as a typical VNF on an x86 processor using the high-speed packet processing framework VPP. For the second BNG implementation, we disaggregate the data plane and implement typical BNG packet processing functions in P4 and deploy them on a programmable switching ASIC while traffic shaping is implemented on an FPGA.

For the benchmark, we create scenarios representing different residential network access patterns, focussing on VoIP and IPTV services, which are sensitive to delay and loss. Therefore, we focus our evaluation on the performance of the BNG data plane, particularly on the enforcement of Quality-of-Service policies. We analyze the following key performance indicators: i) the throughput shaping accuracy for different policies; ii) the packet-processing delay and delay variation; iii) the energy consumption of the BNG data plane.

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Wireless Body Area Network Architecture with Precise Synchronization Services for Advanced Electro-Optical Neuromodulation Devices

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Abstract

Multimodal data analysis is a rapidly growing field of research involving integrating and analyzing data from multiple sources or modalities. This approach has become increasingly important in various fields of research, such as neuroscience, medicine, bioengineering, and psychology, as it allows researchers to gain a more comprehensive understanding of complex phenomena that cannot be fully understood by analyzing data from a single source [1]–[3].

In the medical and bioengineering fields, multimodal data analysis can be used to study the possible effects of some diseases, like epilepsy, on certain physiological signals, such as heart rate, blood pressure, and oxygen saturation [4]. Other examples are the use of bioinformatics for multimodal data analysis in intense care units to help monitor for possible undelaying conditions that are only detectable with a continuous monitorization of the patient's physiological signals [5], [6]. In neuroscience research, multimodal data may be used to study the brain's response to various stimuli or tasks. They may collect data from multiple neuroimaging modalities, such as functional magneticresonance imaging (fMRI) and electroencephalography (EEG), as well as behavioral measures, such as response times and accuracy [7], [8]. By integrating these data sources, researchers can gain a more complete picture of how the brain processes information and how different brain regions interact with each other.

One of the most common issues that have been stated in this area is the difficulty of achieving fine-grained synchronization (sub-second resolution) between all the multimodal signals needed for specific studies, such as Liu et al and Jiang Y et al [9], [10]. This problem becomes more complex as more data acquisition systems are used and as more independent and closed data acquisition systems are used, as is common in medicine and neuroscience. Considering this, the idea of a "Wireless Body Area Network Architecture with Precise Synchronization Services for Advanced Electro-Optical Neuromodulation Devices" was developed. Usually, to solve this problem the synchronization is performed post-acquisition using algorithms and/or machine learning [9], [11] and our main goal is to develop either a device or an architecture of multiple connected devices that will allow to simplify the problem and increase the reliability and precision of performing multimodal data analysis by doing the synchronization at the beginning of the acquisition of the signals. This precise synchronization must be a fine-grained synchronization with a maximum delay between signals below 1 millisecond.

The developments needed will involve multiple areas of research such as embedded electronics, wireless communication, bioengineering, neuroscience, and others. The goal is to have a device(s) that through wireless networks, WiFi and/or Bluetooth, or even (if needed) wired networks, can create a closed-loop real-time synchronization of the data acquisition systems, this needs to be independent of any specific type of acquisition system so that it can be an innovative universal solution. So far regarding this idea, the work already developed has been focused on an ongoing study on developing a synchronization device capable of synchronizing wirelessly (based on artifact creation) Video-EEG and deep brain neurostimulator (Medtronic $Percept^{TM}$ PC) for multimodal neurodata analysis.

For the synchronization of the vEEG and the Medtronic $Percept^{TM}$ PC, there has been only one study publish about this specific subject [12], which is from our laboratory. This paper compares two of the main methods of synchronization: 1) the first method is like the one suggested by Medtronic for fine-grained synchronization; 2) the second method is the "head tapping maneuver" developed by engineering and medical teams from INESCTEC and Centro Hospitalar Universitário de São João. So, the main goal of this ongoing study is to develop a device that allows synchronization of the different devices used for this specific multimodal neurodata analysis. Many synchronization techniques have been studied and documented but for this type of system synchronization, it is important to consider the fact that there is a special interest in obtaining synchronized data from the Medtronic PerceptTMPC, which is a closed system (meaning that the communication protocol is not available, and the device is usually implanted inside the patient). This device when in action will have a visible aspect, for example, a light emitting diode, so that it is visible in the video recording and has the ability to create artifacts in the measured signals in a way that allows a quick and easy way to synchronize all the devices (video, EEG and the Medtronic $Percept^{TM}$).

In the near future, state-of-the-art research will be made on multi-device real-time synchronization with wireless networks. This study aims to investigate and assess various time synchronization protocols to identify the most effective method for achieving real-time synchronization among multiple devices. The objective is to enhance our knowledge of the current state-of-the-art wireless communications, evaluate various applications, and ascertain whether existing research in other fields could address our research objectives. Meaning that technologies and protocols used in industrial settings or Wireless Sensor Networks (WSN) will be accessed to widen the scope of possible solutions already in use in these areas.

In conclusion, this idea is still in definition and starting to be developed but the work already performed, and the planned work ahead reveals promising and viable to greatly improve the synchronization of multimodal data acquisition systems and allow researchers to study multimodal signals/images with higher reliability.

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COVID protection masks effect in Forensic Speaker Recognition

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Abstract

The COVID-19 pandemic represented a challenge for forensic speaker recognition given the mandatory use of protection masks in almost every daily situation, as these act as voice barriers attenuating speech signals. To the best of our knowledge, published research on the impact of facial coverage on forensic speaker recognition notes the need for larger and more diverse datasets, regardless of the significance of the conclusions reached [1]–[10].

Started in January of 2022, a work package, part of the EU-funded CERTAIN-FORS project, aims to tackle this issues by developing a voice samples database to be shared with Forensic Speech and Audio Analysis Working Group (FSAAWG) members of the European Network of Forensic Science Institutes (ENFSI). It has been built with samples obtained from individuals speaking their native language, with and without protection masks, and speaking non-native languages.

The data collection has been performed by several collaborating FSAAWG members, according to a predefined protocol, including: reading a text in native language without mask, wearing a surgical mask and a FFP2 type mask; reading a text in non-native language(s); dialoguing in native language; and, when possible, dialoguing in non-native language(s). The text reading samples were collected consecutively in a controlled environment. The volunteers had total control of the dialogue topic allowing it to be as similar to real case conditions as possible.

The dataset is composed of samples collected from more than 650 volunteers from Croatia, Georgia, Portugal, Romania, Ukraine, Greece, Hungary, Lithuania and Spain. Each collaborating Institute was asked to collect samples from 80 volunteers (40 males and 40 females) minimum, according to the following age classes, in years (ten of each by gender): [18 - 30], [31 - 40], [41 - 50], [51 - +∞[. The characterization of the dataset will be presented, as well as the study of the effect of surgical and FFP2 type protection masks several acoustic parameters. The impact of the Covid protection masks in the performance of Forensic Automatic Speaker Recognition systems will also be evaluated.

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Wavelet Scattering Transform for Enhanced ECG Feature Extraction and Analysis

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Abstract

Electrocardiogram (ECG) signals provide critical information about the heart's electrical activity and play a vital role in diagnosing and monitoring various cardiac abnormalities. Accurate analysis and interpretation of ECG signals are often hindered by the complex nature of the signal, including its quasi-deterministic, non-stationary, nonlinear, and potentially chaotic behaviour. Furthermore, ECG signals are susceptible to various types of noise and artefacts, such as muscle noise, power line interference, baseline wander, and electrode motion artefacts, complicating their analysis. Building upon previous experience in ECG analysis using machine learning, this study aims to explore the potential of the Wavelet Scattering Transform (WST) in enhancing ECG feature extraction and analysis for detecting and characterizing cardiac abnormalities.

The motivation for this study is to leverage the advantages of WST in capturing the intricate time-frequency structure of ECG signals, providing translation-invariant, deformation-stable, and discriminative representations, while preserving high-frequency information even in the presence of noise. It makes WST especially suitable for raw data analysis. WST achieves this by cascading wavelet transforms and modulus nonlinearities, ensuring stability to time- warping deformations and yielding low-variance features. Moreover, WST has demonstrated its potential in biomedical signal-processing applications. For instance, one study reported an accuracy of 99.3% in classifying four types of ECG beats using WST and a K-Nearest Neighbors (KNN) classifier. Another study presented an accuracy of 98.3% in abnormality detection using WST and a Support Vector Machine (SVM) classifier. Previously, two approaches using handcrafted features from raw data, such as R-R intervals, Jitter, Shimmer, and entropies, were designed with MLP and Long Short-Term Memory networks, reaching 92.0% and 98.2% accuracy for atrial fibrillation detection, respectively. These results leave the room for further exploration in feature extraction, and it is believed that WST could be a valuable tool for extracting new meaningful features from ECG signals and improving the classification performance in detecting cardiac abnormalities. Moreover, the lack of studies using WST for ECG classification, the restricted number of abnormities explored in these studies, the not coverage of long-time influences, as at the beat-wise classification works, and the absence of time-frequency methods comparison against WST, create an exploration potential for a definitive update report clarifying the meaningfulness of the time-frequency representations over ECG analysis. When considering traditional Wavelet Transform, the analysis is limited to the lack of shift-invariance, and slight temporal variation on ECG can carry important information. Short-Time Fourier Transform exhibit a non-stable behaviour to rapidly changes on the signal, meaning that deformations due to high frequency noises result in an excessive change in the spectral representation. The Wigner Distribution Function on the other hand, is sensitive to noise, resulting undesirable terms to arise and making the interpretation process difficult.

The proposed methodology involves four main steps: (1) the shaping of cardiac rhythm should be explored trying to reveal biochemical components responsible to produce specific behaviours in normal and abnormal ECG. With this, it's expected to be obtained a reliable model considering some biochemical variables able to better describe cardiac temporal and morphological features, improving the feature extraction process; (2) ECG signal preprocessing, including noise reduction and signal shaping, using various filtering and denoising techniques; (3) ECG feature extraction,

comparing WST with features obtained using other time-frequency analysis methods, like Short-Term Fourier Transform, Wigner Distribution Function and traditional Wavelet Transform, in terms of noise robustness, signal representation, and complexity; and (4) classification of cardiac abnormalities using machine learning algorithms with the ability to handle high-dimensional, sparse, and nonlinear features, such as SVM, random forests, and deep learning models. These models can learn complex decision boundaries and capture intricate relationships between extracted features and target classes, potentially leading to better classification performance.

Expected results from this study include the identification of suitable WST configurations for ECG signal analysis, improved noise robustness and signal representation with WST, and enhanced classification performance in the detection of cardiac abnormalities. Therefore, exploratory activities over WST parameters such as invariance period, length and depth, and its combination with other feature extraction methods like entropies estimation once used, shall be done to evaluate its potential.

Comparing Morphological Traits of Fish Images to Determine Isometric or Allometric Growth

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Abstract

The study of biological scaling relationships of morphological traits is a key component to understand animal growth physiologically and functionally. In the aquaculture industry, the use of imaging techniques allows monitoring of fish growth without removing them from the water, which means less stress and better welfare for the animals, as well as lower cost of weight sampling for fish farmers. Therefore, relationships between weight and traits that are measurable by imaging are important for aquaculture.

Length-weight relationship (LWR) is defined by the equation W = aL^b, where W is the fish weight, L is the total length of the fish, and a, b are experimentally determined coefficients. LWR is commonly used in the aquaculture industry to classify fish species growth as isometric ($b = 3$) or allometric ($b \neq 3$).

The objective of this study is to verify LWR for European seabass (Dicentrarchus labrax) and propose a method based on statistical comparison of model predictions to verify LWR, including non-parametric models. 10 models were developed that achieved an R2 greater than 0.97 and a mean absolute percent error (MAPE) ranging from 3% to 5% for a dataset of 652 lateral images of European seabass (masked and annotated) from 10g to 650g.

The models evaluated included 8 parametric power equation models (W =aD^b), of which 3 were isometric relations where the exponent (b) was constrained to 3, and 5 were allometric relations where both (a) and (b) coefficients were optimized for best predictive performance. The 3 isometric models used as morphological features (D): Total length, standard length, and 36 radius measurements from the center of mass to the contour of the fish silhouette at a series of corresponding angles. The allometric models have (D) as the contour circumference and area of the fish silhouette in addition to the 3 features already mentioned. Two machine learning (non-parametric) models based on a forest of decision trees (Random Forest and Gradient Boosting) were also fitted and tested on the 36 radius measurements.

The dataset of 652 images was randomly divided into two partitions: fitting with 589 images and final test with 69 images. Training and validation with hyperparametrization adjustments were performed in 10 rounds with the fitting partition randomly split into 70% for training and 30% for validation. Validation results were summarized by the mean and standard deviation. The models showed good stability and generalization over the randomly selected partitions. Finally, the model was trained with all samples in fitting partition and tested with the 69 images that had not participated in any of the previous training procedures.

Based on the MAPE metric, the best performance in weight prediction was obtained by the Random Forest algorithm (2.8%), followed by Gradient Boosting (3.3%). The third-place model Allometric

Area (4.3%) is a good option because it is the faster and less resource-consuming model, since it is computed by applying a scaling formula to the number of foreground pixels in the mask, which does not require rotation or translation adjustments as needed to determine radial features.

The fitted allometric models indicated an exponent (b) around 3.019 ($\sigma = 0.013$), which means that 3.0 is in the confidence interval of $\underline{b} \pm 2\sigma$, so it is isometric. Based on the statistical tests (Nemenyi and DSCF) performed for the 10 model predictions (including the isometric ones), we conclude that the European sea bass species can be considered isometric. The tests failed to reject the equality hypothesis with p_{value} 0.05, which means that the growth of European sea bass can be considered isometric.

Bess Operation Assessment Regarding the Rise in the Energy Prices

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Abstract

Introduction

The power system is facing several challenges to evolve to a new system model guided by the energy transition. The main goal of this transition is decarbonization. As for the power sector, it is expected to integrate Renewable Energy Sources (RES) and Battery Energy Storage Systems (BESS) into the Distribution System (DS) and to digitalize the network (Chen et al. 2019). RES weaknesses such as the intermittences (Das et al. 2018) or the need for reaching a more flexible power system have positioned BESS as a promissory technological solution (Saboori et al. 2017) that could offer several services. These facts impact on the power system planning and operation since RES are well spread into the DS. In the literature, the most common BESS operation strategy used is to respond to the energy market prices (EMP), but EMP has reached record levels in 2022, even more than doubled (OMIE 2022). Rises that are mainly linked to COVID-19, the Russian-Ukrainian war, and climate change. In this scope, it is important to identify how the rise in EMP may impact on BESS operation.

Materials and Methods

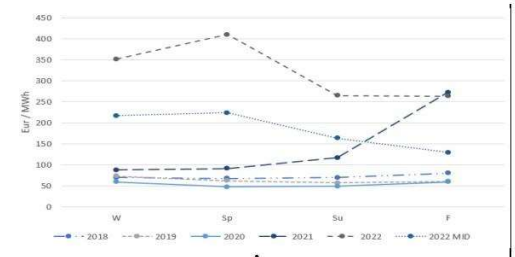
For analyzing how the rises in EMP impact on BESS operation an optimization model similar to that previously described in Abreu et al. 2019 is approached to respond to the EMP. Based on the historical data recorded from the Iberian Market from 2018 to 2020 and 2022 (OMIE, 2022), the rises in EMP led to an important data dispersion that makes it essential to find a way for representing unexpected values. Then, curves(2018 to 2020 and 2022) were statically categorized for characterizing their behavior in a histogram and finding the curve that fits those data. The curves fit from the histograms allowed us to consider from a sequence of random numbers ζ must be generated from a uniform probability distribution from creating a database scenario that fits the expected values but also the unexpected ones. This method is repeated for a whole year for generating a series where every day is represented by 24 periods. By following this selection process, the database will not be grouped by season, the season data is dispersed throughout the year instead, which guarantees a larger sampling dispersion conditions and also the evaluation of different alternatives, not only minimum and maximum points. Finally, the database is used as an input for the optimization model.

Results and Discussion

This section reports (i) the EMP data available and the scenarios generated for assessing the optimization model, and (ii) the BESS operation results and analyses (when BESS responds to EMP). Figure 1A shows the EMP values from 2018 to 2022. Values up to 400 E/kWh were recorded in Spring 2022, nevertheless, reductions were also recorded for Summer/Fall. In contrast to 2018 to 2020, EMP was high enough in 2022 to be considered more than doubled.

Then, it was analyzed how these facts impact on BESS operation. For this, the process mentioned in section 2 was followed to obtain 20 databases for EMP from 2018-2020 and 20 for EMP 2022. It was considered BESS operates with 0.1 of SOCmin, 0.5 of initial SOC, different charge/discharge rates (Crate), and 90% of round-trip efficiency (η). Figure 1B shows a comparative table of BESS operation cycles per week. As noted, there are slight differences in BESS operation regarding rises

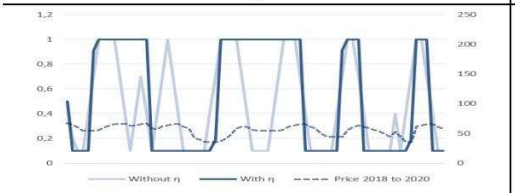
in EMP in 2022. Differences are more relevant when BESS η is modeled (see Figure 1C and 1D). This allows us to highlight why BESS operation models must consider performance criteria as they are more relevant for its operation than the rise in EMP.



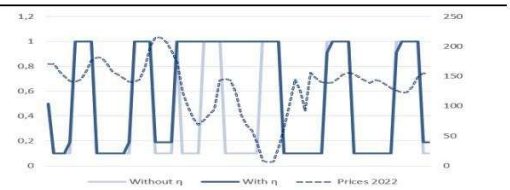
A

Crate	Prices 2018 to 2020		Prices 2022	
	With η	Without η	With η	Without η
0,3	4	18	5	19
0,5	5	19	6	19
0,7	7	19	9	20
0,9	10	16	11	20

B



C



D

Figure 1: (A) Energy prices per season/year; (B) Comparative table of BESS operation cycles per week; BESS operation with and without η for (C) 2018 to 2020 EMP and (D) 2022 EMP (over 3 days).

Conclusions

Analysis of how relevant the volatility/rises in EMP is for BESS operation revealed after evaluating 20 scenarios database that rises do not significantly modify BESS operation. On the contrary, to consider BESS performance criteria are relevant enough to modify BESS operation. Thus, BESS operation is more critical when its model is restricted by performance criteria. Undoubtedly, the rises in EMP prices impact on the BESS operation cost as BESS operation responds to them, but these analyses were not in the scope of this document.

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Posters to be displayed in the Symposium

Context-Aware Reinforcement Learning for Supporting WiFi Connectivity for Vehicles

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Abstract

The continuously rising number of mobile users and applications drives spectrum scarcity. WiFi connectivity can help to reduce the load on cellular networks in urban areas for slow moving commuters if supported by adequate network management. This research explores reinforcement learning using context and network data to deal with the stochastic and dynamic nature of WiFi and provide continuous connectivity to a moving vehicle. We formulate the access point handoff problem as a Markov Decision Process (MDP) and solve it using Deep Q Network (DQN) applied to a real-world dataset. The observed pattern of learning in preliminary results indicates that the agent can learn from the real world dataset.

Towards an End-to-End Energy Model for Virtualized RANs

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Abstract

Radio Access Networks (RANs) account for around 75% of mobile networks' energy costs, with Core Networks taking over the rest. For the past decade, Power Amplifiers have been the major power consumers in Macro-Cell Base Stations (BSs). However, the rapid proliferation of Small-Cell BSs is changing this paradigm. In modern BSs, computation is the dominant power-consuming activity, rendering Baseband Units (BBUs) the primary hardware component responsible for power consumption. The energy efficiency of BSs has increased over the last generations (3G, 4G), mostly driven by improvements at the hardware level. Today, the shift in BS's power-consumption breakdown, coupled with the advent of virtualization and disaggregation, opens up opportunities to improve the energy efficiency of BSs at the software level.

Over the last decade, research has come up with key insights into the energy consumption of BBUs. It has demonstrated that baseband processing accounts for approximately 50% of 5G base stations' energy consumption, with modulation, demodulation, coding, and decoding functions dominating computing resources. While these results hold for monolithic base stations, they are challenged by virtualized and disaggregated BSs. Besides, these BSs introduce new dynamics between disaggregated components (UEs, DUs, CUs), their configurations, and even channel conditions.

An important step towards the energy efficiency of 5G BSs is to understand to which extent different functions in the 5G pipeline influence the energy consumption of a BS. This knowledge can be applied to dynamically adapt parameters related to an ongoing User Equipment (UE) session (e.g. the Modulation and Coding Scheme) or even the BBU's configuration (e.g. number of threads), for example. We argue that an energy model is instrumental in achieving this goal, and we have set out to propose one. This effort calls for a holistic approach that takes into account the interplay between the different functions in the 5G pipeline, and the influence of factors that are either exogenous (e.g. channel noise) or endogenous (e.g. threading configuration) to the system under analysis.

This work introduces the first steps toward proposing an end-to-end energy model for RANs. First, we present a fully open-source private 5G RAN that is being deployed at FEUP as a testbed to validate our models. Second, we present preliminary results on the relationship between 5G protocols and their processing requirements, which hint at the energy requirements of 5G BSs.

Man-Machine Symbiosis: Towards an implicit and affective relationship between man and machine

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Abstract

The concept Man-Machine Symbiosis was first mentioned in a work by Licklider named "Man-Computer Symbiosis" in 1960 [1]. The author defended that (intelligent) technology should be developed to augment human intelligence, not replace it, turning the typical user-centered application into a distributed system. This idea at the time did not have many followers, however, nowadays it is a relevant concept in a world where humans need to interact with machines on a daily basis.

There are already in the literature many examples on human-machine interaction, but most of them describe explicit interaction between man and machine. This type of interaction occurs when, man or machine, explicitly send a command or information to the other. Despite explicit communications being important, we defend that having a way to implicitly communicate with the other member is a mandatory feature for the next generation of human-machine symbiotic systems. A machine should implicitly understand what human intentions are and perceive if an atypical situation occurs. Similarly, the human should also understand what the machine's goal is and if something wrong has happened to it.

In our concept of Man-Machine symbiosis, the human physiological data, such as the electrocardiogram (ECG), electromyogram (EMG), electroencephalogram (EEG), body temperature, movement, and others is continuously measured using wearable devices. This information is aggregated and synchronized using a processing unit. Psychophysiological features , such as human stress levels, respiration and heart rate, heart rate variability metrics are then calculated, and an estimate of the human psychophysiological state is computed [2]–[4]. This information is then broadcast and injected into the machine control loop through a module named man-machine symbiotic engine. With this information the machine will be able to implicitly perceive changes in its human state or behavior.

Regarding requirements for the referred components, the wearable devices should not interfere with the actions and movements that the human is expected to perform. Size and weight are then aspects to consider during the implementation of the system. Furthermore, using wireless communications technologies between the sensing devices and processing unit, such as Wi-Fi and Bluetooth, is important reducing the bulkiness of the system. For the processing unit having a user interface (GUI) is also interesting to have for explicit man-machine communication. Interesting devices to use are Android smartphones or mini pcs such as a raspberry pi [5], or a nvidia jetson [6] with a touchscreen.

In the other side of the relationship the machine also has a group of sensors that are needed for its operation such as Inertial Measurement Units (IMU), GPS sensors, Vision sensors and others. Similarly to the human, this information is aggregated and processed through a processing unit. This unit is also responsible for hosting the man-machine symbiotic engine acting as the "brain" of the machine. The engine will receive psychophysiological information regarding the human and data from the machine sensors and then decide if the machine should keep its autonomous work or stop and check any abnormal condition on its human. This engine should also have real-time

learning capabilities allowing, for example, the association between measurements from the machine sensory devices with the received human state. This will allow the machine to learn how to have a more affective response while facing certain situations.

In the machine's case, the sensors' requirements must be constrained to the size and power of the machine. About the processing unit although it can be as big as regular sized pc, we suggest the use of a GPU powered mini pc such as the nvidia jetson [6].

An example of this technology has been developed applied to search and rescue in catastrophic scenarios such as earthquakes or floodings. Here the first responders act as the human component and an unmanned aerial device (UAV) is used as a machine to aid them in their operations. This system has been tested in a Joint Interagency Field Experimentation (JIFX) event hosted by the Naval Postgraduate school [7].

On this event we successfully merged the work on human sensing technology developed in Portugal with the UAS system built by our partners on Carnegie Mellon University. We built a user bio identification system using ECG based on a work developed by Paiva *et all* [8]. Furthermore two explicit communication modules, one using a Brain-Computer Interface (BCI) based on the Filter Bank Common Spatial Pattern algorithm [9] and the other using eye blinks were developed. A proof-of-concept of an initial symbiotic system with both implicit and explicit capabilities was then built and demonstrated during the event.

Future work for this project includes testing of the current capabilities of the system and further work in the man-machine symbiotic engine bringing real time learning capabilities to the machines, aiming for a more harmonious and natural interaction with humans.

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Towards reducing resource consumption of ML and DL algorithms in Embedded Systems

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Abstract

Introduction

Our research addresses the challenges of deploying computationally intensive ML and DL models in resource-constrained embedded systems. We specifically investigate the impact of data dimension and algorithm complexity on model efficiency. Our preliminary results demonstrate the influence of dimension reduction on inference time, particularly for IoT network anomaly detection models. We aim to enhance the applicability of ML in embedded systems by overcoming limitations in handling diverse ML models. In our ongoing research, we will explore additional factors and propose methods to improve resource usage and efficiency. Our ultimate objective is to provide practical solutions for efficient ML deployment in embedded systems.

State of Art

Researchers have proposed several methods to optimize ML and DL models for deployment on embedded systems. For instance, model selection optimized for embedded constraints while reducing complexity and maintaining performance has been proposed [1]. Reducing model complexity, such as compressing neural networks into fewer parameters, has been used to optimize object detection and disease detection [2, 3] respectively. Additionally, feature selection methods have been employed to enhance performance while minimizing time complexity in various classification algorithms [4]. While many techniques have focused on optimizing neural networks for embedded systems, recent studies have shown that non-deep learning ML algorithms can also be practical. However, there is a lack of research on the factors that affect the performance of a wide range of ML models in embedded systems. Therefore, our goal is to propose efficient methods for reducing resource consumption while maintaining model performance to make ML more accessible to various embedded systems.

Preliminary Work

We carried out some preliminary experiments concerning the execution time of different models in an IoT anomaly detection use case. The experiment was conducted on a machine running Windows 10, with 16GB RAM, a 6-core CPU, and Python 3.8. The ”Train Test Network data set” used in the experiment is a subset of ToN-IoT [5] and was subjected to data cleaning. Sklearn library was utilized for implementing algorithms, with an 80:20 split for training and testing sets. GridSearch cross-validation was used to identify the best hyperparameters for each model. Then we carried out data dimension reduction from 39 to 9 using autoencoders .

Results and Discussion

We evaluated the performance of four common supervised models: Logistic Regression (Log Reg), K Nearest Neighbors (KNN), Random Forest (RF), and Support Vector Machine (SVM). The evaluation was based on Accuracy, Detection Rate, False Positives Rate (FPR), Precision, and inference time in seconds. We found that dimension reduction had a significant impact on the inference time of the KNN model, resulting in a remarkable reduction of approximately 100 times. This highlights the effectiveness of dimension reduction in improving the efficiency of the KNN algorithm. Among the evaluated models, Log Reg exhibited the fastest inference time, while SVM was the slowest. Interestingly, we observed negligible changes in performance metrics, such as Accuracy, Detection Rate, FPR, and Precision, across the different models.

Table 1: Metric for the four common models with two data dimensions

Model	Accu.	Detect	FPR	Precision	Inference time(s)
Sample with 39 features					
Log_Reg	0.9048	0.98199	0.1723	0.7536	0.008619
KNN	0.999	0.999	0.0012	0.9976	215.97
RF	0.9829	0.997	0.031	0.9441	3.067
SVM	0.9020	0.9728	0.1687	0.755	333.916
Dimension reduction to 9 features					
Log_Reg	0.896	0.9627	0.1705	0.7518	0.0029
KNN	0.9988	0.998	0.0013	0.9975	2.16
RF	0.9942	0.9980	0.0095	0.9825	2.933
SVM	0.9057	0.9843	0.1728	0.7535	152.87

This suggests that dimension reduction did not have a substantial impact on the overall performance of the models. While the current study did not include preprocessing time, we acknowledge that it is an important factor to consider for a comprehensive analysis of resource consumption. Future work will explore the inclusion of preprocessing time to provide a more accurate assessment of inference time in practical scenarios.

Future Work

In our future work, we will employ a system-level methodology to optimize re- source utilization in embedded systems by analyzing factors such as algorithm scalability, feature selection techniques, and hardware considerations to obtain significant insights into enhancing resource consumption and improving performance. Furthermore, we will incorporate a wider range of resource metrics, encompassing memory usage, energy consumption, and CPU usage, to gain a comprehensive understanding of the specific resource requirements. By addressing these aspects, our objective is to enhance the overall efficiency and effectiveness of models deployed in embedded systems with limited resources.

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