

PhD Candidate full name:

Tamás Karácsony

Dissertation Title: Advancing AI in Healthcare: Action Recognition and Human Pose Estimation for Epileptic Seizure Classification

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Abstract or Public Summary: One of the emerging frontiers in artificial intelligence (AI) applications lies in clinical diagnostic support. With the unprecedented growth of health data, there is an increasing clinical need for methods that can analyze, quantify, and classify such information effectively. In this thesis, we address one of the most challenging use cases in this domain, clinical in-bed patient movement monitoring for semiology-based epileptic seizure classification. Seizure semiology, or the characteristic movement pattern during epileptic events, holds significant diagnostic value; however, in current clinical practice, it is typically assessed through qualitative visual inspection of video recordings obtained in Epilepsy Monitoring Units (EMUs). To enhance this process, we propose a framework that leverages AI-based classification and quantification techniques, integrating state-of-the-art action recognition and Human Pose Estimation (HPE) methods. This work required the extraction and classification of four-dimensional (4D) temporospatial movement features within an inherently data-scarce clinical environment characterized by a low signal-to-noise ratio. Only a subset of movements visible in the video recordings, called Movements of Interest (MOIs), carry clinically relevant information, and these are often partially occluded by blankets, other objects, and/or people. After identifying the core challenges associated with this process, we addressed them through three main research directions. First, to address the scarcity of clinical data, we developed and deployed “DeepEpil”, a cloud-based system designed to facilitate collaboration with the Epilepsy Clinic of Ludwig Maximilian University of Munich (LMU). Through this platform, we curated multiple datasets from existing clinical video recordings (IR-D, and 720p/1080p RGB) and expanded our collaboration to include Centro Hospitalar Universitário de São João (CHUSJ), our Portuguese clinical partner, for comprehensive evaluations. To future-proof the data acquisition pipeline, we designed and installed NeuroKinect4K hardware in three EMU beds at LMU, enabling the continuous collection of 4K RGB-D-IR recordings. Using this infrastructure, we generated several specialized datasets, including an MOI simulation dataset, comprising seizure movements

simulated by multiple clinicians in EMU settings, and BlanketSet, a blanket-occluded action recognition dataset. In parallel, we have been continuously collecting clinical data to support future research and applications. Second, as HPE is exceptionally challenging in bed scenarios due to the regular blanket occlusion, we developed synthetic blanket occlusion augmentation pipelines to improve HPE (BlanketGen, BlanketGen2). We showed that utilizing this synthetic data for fine-training HPE architectures, teaching them the visual features of the dynamic blanket deformations, can improve HPE under blanket occlusion, and even showed a promising impact when transferred and tested on real-world in-bed blanket occluded data. Additionally, utilizing automated HPE based on transformer Deep Learning (DL) networks, and a more classical, optical flow-based, semi-automated approach for tracking, we quantified seizure movements, where we showed statistically significant differences between seizure classes on clinical data. We also showed that 3D visualizations of these movement patterns may be beneficial in the future for clinical practitioners. Third, we demonstrated epileptic seizure-related action classification on both simulated MOIs, in collaboration with technical partners at Carnegie Mellon University (CMU), and on real clinical seizure data, using multiple image- and skeleton-based action recognition approaches. With image-based methods, we achieved near real-time, three-class classification on clinical IR-D seizure recordings and seven-class MOI-level classification on 4K RGB data. With the later we also highlighted the multiscale challenge of this classification problem. In contrast, skeleton-based approaches showed greater potential: we obtained four-class MOI classification from skeletons extracted from the simulated 4K RGB dataset, and up to five-class classification using skeletons derived from 1080p clinical seizure videos. Validation on clinical data with DL transformer-based skeleton action classifiers produced promising results, further indicating that, in highly data-scarce scenarios, classical machine learning models based on movement quantification may still offer valuable performance. Across all cases, transfer learning proved essential to achieving robust outcomes under limited data conditions. This thesis presents the research conducted on AI for clinical diagnosis support, focusing on the vertical of semiology-based seizure classification. It addresses the complete AI-driven diagnostic support pipeline, encompassing action recognition, HPE, data acquisition, and Machine Learning Operations (MLOps). The work results from a multidisciplinary and multi-continental collaboration involving INESC TEC, academic partners such as FEUP and CMU, and clinical institutions including LMU Klinikum and CHUSJ. By bridging AI and clinical neurology, this research lays the groundwork for future AI-assisted diagnostic support and continuous patient monitoring, enabling large-scale clinical validation and advancing integration into real-world diagnostic systems.

Principal Supervisor at INESC TEC: João Paulo Cunha

Additional Supervisor: Fernando De la Torre (Robotics Institute, Carnegie Mellon University)

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