

## Abstract

In the ever-evolving landscape of healthcare, the convergence of biomedical engineering and technological innovation stands as a beacon of progress. This thesis is a testament to the fusion of engineering principles with the intricacies of medical science, particularly in the realm of biomedical signal analysis. The human body, an amalgamation of interconnected systems, embodies a symphony of functions orchestrated by the cardiovascular, Musculo-skeletal, and nervous systems. Our exploration delves deep into the significance of understanding these systems through the lens of biomedical signals—key conduits revealing the body's nuanced physiological processes and early indicators of potential ailments.

Advancements catalyzed by the 4th Industrial Revolution have heralded a new era in healthcare. Technologies like AI, IoT, wearable devices, telemedicine, and 3D printing are reshaping the landscape, rendering healthcare more personalized and accessible. Amidst the burgeoning global population and the surge in communicable and non-communicable diseases, these innovations stand as stalwarts in addressing the challenges faced by the healthcare domain.

Within this context, signal processing emerges as a linchpin in interpreting biomedical signals—ECG, EEG, and EMG—signals that, despite their pivotal insights, present challenges due to their complex and non-stationary nature.

This thesis sets out with a clear objective: to traverse the domains of biomedical signals, shedding light on their quintessence in healthcare science and technology. We aim to bridge the gap between established methodologies, rooted in electrical engineering and statistical analyses, and a deeper comprehension of the underlying scientific principles governing these signals. Our journey unfolds through the exploration of nonlinear dynamics—Chaos, Fractals, and Entropy—as potent tools for modeling the intricacies within cardiovascular, nervous, and musculoskeletal systems. The complexities inherent in these signals demand methodologies beyond conventional linear approaches, prompting our foray into nonlinear time series analysis.

Methodologically, this thesis charts a course encompassing signal acquisition, meticulous denoising, and the deployment of Nonlinear Discrete Dynamical Systems to dissect the essence of ECG, EEG, and EMG signals—treating them as dynamic, nonstationary time series of discrete samples. Throughout our odyssey, Chaos analysis, leveraging the Largest Lyapunov Exponent, endeavors to measure the divergence rate of phase space trajectories. Concurrently, Fractal Dimension estimation discerns signal complexity through scaling behavior, while Entropy becomes our compass in navigating information transfer and unpredictability within these signals. The culmination of these analyses yields parameters serving as veritable descriptors of dynamic system states. These descriptors, meticulously extracted, are then harnessed to fuel machine learning models—Artificial Neural Networks, Support Vector Machines, Random Forests, and Decision Trees—for classification, regression, and predictive analytics.

Our voyage extends into experimental terrains, encompassing cardiovascular, neurological, muscular, and neuromuscular systems. Rigorous experiments involving EMG and EEG signal analyses unfold, capturing the essence of Motor Unit Action Potentials and neural dynamics associated with cognitive actions.

Ethical tenets stand as our guiding light in human subject experiments, ensuring the sanctity and integrity of our scientific pursuits. Notably, our contributions manifest in the formulation of an algorithm—a beacon of innovation—dedicated to the detection of sleep apnea from single-channel ECG signals. This algorithm intricately leverages Multiscale Entropy analysis during apnea events, a testament to our commitment to actionable applications rooted in robust scientific principles.

In summation, this thesis embarks on an expedition into the frontiers of Chaos, Fractal Dimension, and Entropy, aiming to decode the enigmatic language of physiological signals. Our endeavors are poised to amplify the understanding of system dynamics, laying the groundwork for these analyses to serve as indispensable features in diverse healthcare applications.

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