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# Advances in Electrodermal Activity Processing with Applications for Mental Health

## From Heuristic Methods to Convex Optimization

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# Foreword

This book presents a critical review of methodological studies for the analysis of the electrodermal activity (EDA), one of the most powerful noninvasive peripheral measures of the autonomic nervous system (ANS) neural pathway. Through the book, the author leads the reader from a thorough description of electrodermal physiological phenomena to an advanced introduction and discussion of recommended techniques for correct data collection and effective data analysis. Several experimental setups are also presented.

Although the EDA signal is fairly easy to acquire and very informative, powerful methodologies and efficient models are required to make meaningful inferences on the dynamics at the central nervous system level. The book introduces and emphasizes a novel computational model for EDA analysis that I have personally promoted and coauthored. The method relies on rigorous mathematical techniques, such as convex optimization, to provide an effective window on the ANS dynamics, and it has been successfully applied in several experimental scenarios. EDA is a source of many sensitive psychophysiological markers and it finds application in several fields of research, such as psychology and medicine, as a viable indicator in emotion assessment and pathological mood state recognition. Remarkably, the book presents several experimental applications exploring different sensory channels for emotion stimulation in both healthy subjects and bipolar patients with very promising results.

I am confident the reader will find useful information on proper characterization of EDA dynamics and how this can be applied to the rising fields of affective computing and psychophysiology. The high technical content makes the book attractive to anyone interested in signal processing, statistics, applied mathematics, and physics.

The book is a valuable reference for active research scientists and postgraduate students interested in methods at the interface of bioengineering and statistics. I expect that this book will stimulate and encourage the use of such methods in different fields of applied science.

Colchester, UK — Dr. Luca Citi
August 2016

# Preface

Electrodermal activity (EDA) can be considered one of the most common perceptual channel, of the autonomic nervous system (ANS) dynamics and manifests itself as changes in electrical properties of the skin. Several previous studies have shown how EDA can be a very informative biomedical sign with high discriminant power between different psychophysiological states, although in this case many methodological issues arise. This book fervently shows how to retrieve much reliable information from EDA, to investigate also the assessment of emotional responses in healthy subjects and patients with pathological mood/mental states. Throughout the chapters, in-depth methodological and applicative studies involving EDA are described, including a critical review on the current state of the art. Since continuous deconvolution analysis (CDA) has been recognized as one of the mostly used methods for EDA analysis, we first show how to apply this model to discern different affective states in healthy volunteers. Emotions were evoked using multimodal standardized sets of pictures, sounds, caresses, and smells. Valence and arousal levels of such emotions were identified as the principal dimensions of the affective responses. The achieved results are consistent with the hypothesis that it is possible to objectively study ANS dynamics involved in the emotional processing by properly processing the EDA.

Furthermore, this book reports on a novel computational model for the EDA analysis based on convex optimization methods. This model, hereinafter called cvxEDA, describes the EDA as a sum of the phasic component, the tonic component, and an additive white Gaussian noise term incorporating prediction errors, as well as measurement errors and artifacts. CvxEDA is physiologically inspired and overcomes the limitations of the heuristic solutions and post-processing steps of the conventional approach. It is based on a rigorous methodology grounded on Bayesian statistics, mathematical convex optimization, and sparsity. Building on our previous CDA-based experimental results, outcomes of cvxEDA often demonstrate higher accuracy than CDA while discerning elicited emotional states in healthy subjects. When applied to EDA from psychiatric patients suffering from bipolar disorder, it is shown how EDA significantly changes according to different mood states. This also allows using EDA phasic and tonic components as suitable markers for discriminating pathological mood states in bipolar patients.

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# Contents

# Acronyms and Symbols

The following table shows the most used and important acronyms.

| Statement | Acronym |
|---|---|
| Autonomic nervous system | ANS |
| Central nervous system | CNS |
| Electrodermal activity | EDA |
| Electrodermal response | EDR |
| Electrodermal level | EDL |
| Skin conductance | SC |
| Skin conductance response | SCR |
| Skin conductance level | SCL |
| Non specific skin conductance response | NsSCR |
| Heart rate variability | HRV |
| International Affective Picture System | IAPS |
| Circumplex model of affect | CMA |
| International Affective Digital Sounds | IADS |
| Continuous deconvolution analysis | CDA |
| Signal-to-noise ratio | SNR |
| Finite impulse response | FIR |
| Infinite impulse response | IIR |
| Impulse response function | IRF |
| Auto-regressive moving average | ARMA |
| Auto-regressive | AR |
| Moving average | MA |
| Area under the curve | AUC |
| Respiratory volume | RV |
| Respiration activity | RSP |
| Skin temperature | ST |
| Pupil diameter | PD |

| | |
|---|---|
| Impedance cardiogram | ICG |
| Heart sound | HS |
| Linear discriminant analysis | LDA |
| Artificial neural network | ANN |
| Support vector machine | SVM |
| Canonical correlation analysis | CCA |
| Stepwise discriminant analysis | SDA |
| Classification and regression tree | CART |
| Quadratic discriminant analysis | QDC |

# Introduction

This book is intended to provide an exhaustive description of the electrodermal activity (EDA), from a deep insight onto the physiological foundations to ad hoc algorithmic methods to analyze it. Expected audience ranges from researchers with expertise in signal processing who would like to approach EDA analysis for their first time, to experienced EDA researchers aimed to take into account recent advances in EDA sparse modeling. Proper links to MATLAB software for EDA analysis are also provided (see Chap. 2). Our principal aim is to show how EDA can be at the center of breakthrough investigations involving the autonomic nervous system (ANS) activity, being also a source of reliable and effective biomarkers of healthy affective responses and pathological mood/mental states.

EDA manifests itself as a change in electrical properties of the skin, i.e., skin conductance (SC). There are two main components of EDA having different time scales and relationships with exogenous stimuli: the tonic and phasic components.

In the first part of the book, we describe the electrodermal physiological phenomena underlying SC variations. Moreover, we include a critical review on the current state of the art concerning EDA application, analysis methods, and recording systems for both laboratory settings and ecological scenarios. The description of a recently proposed recording system which uses different frequencies for the demodulation of EDA components is also emphasized. Importantly, despite the widespread use of EDA device-related measurements, the actual biological phenomena underlying EDA (i.e., skin sympathetic nerve activity) remain unknown. Therefore, in the last decades, several mathematical models were developed to overcome this limitation, trying to investigate on how ANS activity regulates the EDA dynamics. In this book, we rely on the classical model describing SC as the sum of three terms: the phasic component, the tonic component, and an additive white Gaussian noise term incorporating model prediction errors as well as measurement errors and artifacts.

In this part of the book, we also emphasize a recently proposed, physiologically inspired EDA model based on a rigorous mathematical approach, grounded on Bayesian statistics, convex optimization, and sparsity. The phasic component is seen as the result of a convolution between a bioinspired bi-exponential impulse response function (IRF) and a sparse signal representing the sudomotor nerve activity, which is part of the ANS. The IRF is modeled as an IIR filter allowing a much more compact and non-banded matrix representation increasing the accuracy and reducing the computational cost. Unlike previous algorithms in the literature, this model incorporates the intrinsic physiological characteristics of EDA without necessarily resorting to heuristics and ad hoc solutions, thanks to the presence and definition of prior probabilities for the phasic and tonic signals. Results were compared to those obtained through the continuous deconvolution analysis (CDA) model [1], a method that performs a deterministic inversion of the peripheral model. The proposed method showed good performance confirming a promising applicability in the field of affective computing as well as of mental health.

In the second part of the book, we report on several EDA application scenarios, especially related to two specific research fields: emotion recognition and assessment of mood/mental disorder. Indeed, emotions and mental disorders are strictly and intrinsically interrelated; therefore, when emotions are dysregulated, mental health is not guaranteed. Affective experiences accompany all cognitive processes and social activities even in the case of psychopathologies [2, 3]. Moreover, prevalent theories affirm that the emotional processes can have primacy over cognition [4]. As an example, the regulation process of emotions is crucial in the occurrence and control of major depressive episodes, and some theoretical views of depression are based on emotion changes which have implications in the assessment, treatment, and prevention of the pathology [5]. Another well-known relationship between emotions and mental disorders regards anxiety [6] as well as brain damages of emotional processing areas and decision-making process [7].

In this part of the book, several experimental results gathered from testing EDA models to robustness to noise, ability to separate and identify exogenous stimuli, and capability of properly describing the activity of the autonomic nervous system in response to specific affective elicitation are reported in detail. Concerning the affective elicitation paradigm, we show exemplary applications of EDA modeling on data gathered from healthy subjects undergoing multimodal affective elicitation, where visual, auditory, olfactory, and tactile stimuli were investigated. Concerning the mental health scenario, EDA analysis was employed to assess patients with bipolar disorder [8–10], who experienced depressive and manic or hypomanic episodes. Data used for this study were acquired in the frame of a European collaborative project called PSYCHE (personalized monitoring systems for care in mental health) [8, 11].