Psychophysiological signal analysis and classification

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Abstract
In this position paper we describe the research scope, past and recent results, engineering challenges and the promising approaches the authors are investigating in their work on psychophysiological signal analysis and classification applied to automatic affect recognition, HCI, artistic performance and emotion research.

Keywords
Physiology, signals analysis, machine learning, affective computing

ACM Classification Keywords
HCI

Introduction
Affective computing links human emotional states to computer systems. Our interest in this field relates to enhancing human-computer interaction (HCI), aiding in emotion research and developing therapeutic applications for people with emotional disabilities. These objectives require the design of automated systems capable of identifying and interpreting human emotions in real-time based on physiological signals from a wide array of sensors that measure manifestations of the autonomous nervous system. The sensors include body-worn devices and cameras,

the latter which allow for automatic classification of emotional states through the analysis of facial expressions. This capability is particularly important for applications requiring greater ergonomics, less intrusive sensing methods, and lower costs. Regardless of the sensing method, our approach relies heavily on robust signal processing and pattern recognition techniques to provide fast and accurate emotional state classification.

Research scope

Our research on automatic classification of emotional states has focused on the development of signal processing and machine learning techniques. Using physiological measures (galvanic skin response, heart rate, heart rate variability, blood volume pulse amplitude, pulse transit time, phalange temperature, respiration, facial electromyography) as input, we have studied the design of signal processing algorithms and pattern recognition systems that perform classification with respect to either a continuous valence and arousal scale or discrete emotional states [1]. Recent applications include theatrical performance, where the actor's live emotional state was used to generate audio and visual media on stage; the study of music and affect, where the listener's emotional responses were compared to structural elements of music; brain imaging experiments, where the physiological responses to emotional stimuli were used to model pleasurable affective states [2]; and in HCI, where measures of emotional stress derived from the biosignals were used to evaluate different interaction modalities [3].

In addition, we developed a real-time, automatic facial expression classifier as a tool for therapeutic applications. This research activity involves collaboration with psychologists to develop games that will help in facial expressivity, a major social impediment for children diagnosed with autism spectrum disorder.

As the technology has matured, we are now expanding our research to explore further applications including gaming, usability evaluation and human factors design.

Significant contributions to the field

We collected a dataset of physiological signals, designed signal processing algorithms to filter and condition these, and developed the machine learning methods to classify four different emotions with an accuracy of 90% [1]. For dataset collection, we obtained highly accurate, emotionally relevant biosignals by working with a method actor as the subject. She was able to exploit her training and experience to truly "feel" what was asked by a theatre director. Our classification results set a new benchmark for affective computing recognition as they surpassed the accuracy reported in previous research for subject-dependant systems.

For another study in collaboration with neuropsychologists, our algorithms were applied for signal conditioning, processing, and statistical analysis. The research investigated the psychophysiological and neurological responses to pleasurable and chills-inducing music [2] for 38 subjects. This included brain imaging, measurement of physiological signals, and precise, continuous self-reported ratings, allowing for validation of the data against ground truth labels.

Finally, we used physiological signals in an HCI perspective to measure the induced stress levels resulting from the use of different input modalities for a 3D interaction task [3] and from network latency in a distributed musical performance context [4]. For the 3D interaction task, the findings demonstrated significant effects of stress between the input devices tested, and similarly, in the musical performance case, between different latency conditions. These results validated the use of physiological measures, and to our knowledge, represented the first studies to adopt such objective metrics as opposed to relying exclusively on self-report questionnaires. We expect this approach to be used again in future interaction experiments.

Engineering challenges and promising approaches

Reliable classification by pattern recognition systems depends critically on the use of noise-free features as input. As affective computing applications gain popularity outside of the highly controlled laboratory environment and begin to be used for a wide range of tasks in the home, therapy center, and theater, special attention must be paid to robustness to a variety of possible noise sources. However, we are constrained to lightweight signal conditioning algorithms as most applications demand real-time operation. The use of physiological signals poses filtering challenges, since we must consider both environmental and biological sources of noise. As the physiological sensing equipment is designed to capture very small electrical potentials (some on the order of μV), it is highly susceptible to interference from other bodily systems as well as the power grid main. Each signal must therefore be associated with a filtering method specific to its particular biological properties. Another important source of noise is body movement, which induces jitter at the electrode-skin junction. One possibility worthy of further investigation as a means to cancel out the resulting large fluctuations in the raw data is adaptive non-linear de-trending functions. These continuously model the additive movement artifact waveform and subtract it from the signals.

As a rule, emotion recognition requires machine learning. This is necessary for robust recognition in general and equally critical, to discriminate emotional states among multiple individuals, each with their own personal physiological traits, on whom the system has not necessary been trained explicitly. As the data collection process is an arduous task, it is highly desirable to develop pattern recognition techniques that can generalize effectively from training data sets of limited size, while still providing accurate classification across many users. A key step in pattern recognition is the identification of salient features in the data that optimize the emotional-class discrimination and generalization power of a classifier. As these are improved, calibration time for new users can be reduced and may eventually be nullified. Encouragingly, our work in this field led to the development of feature selection and transformation methods that achieved high levels of class separation on a small subset of users. Moreover, our planned refinements of this process, e.g., using non-linear dimension reduction methods such as generalized discriminant analysis [5], offer significant potential to improved generalization and thus, dramatically reduced training time.

Primary author’s biography

Formal training in electrical engineering with control systems and information technology specializations has exposed the main author to both classical and state-of-the-art signal processing and programming techniques. Proficiency in machine learning, computer vision and human-computer interaction has also been acquired through graduate-level courses taken during his doctoral studies. Furthermore, an extensive knowledge of the psychological and physiological literature has contributed to his ability to design signal processing algorithms adapted to human biology. He is thus able to implement every stage of an automatic pattern recognition system, from the acquisition and processing of the raw input signals to the design of fast and robust machine learning models.

Conclusion

This paper briefly presented some of our scientific interests and contributions to the field of psychophysiological signal analysis and classification. Affective computing, brain imaging, emotion research and HCI applications were discussed. Importantly, the methods developed have produced some of the highest classification results in the literature. With respect to the present workshop, our expertise in signal processing, machine learning and human psychophysiology in addition to our experience in multi-disciplinary collaborations ensure valuable contributions that will further advance its research themes.

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