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Algorithms for Affective and Ubiquitous Sensing Systems and for Protein Structure Prediction

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Abstract

Rapid development in sensing technologies has facilitated increased design of more affective and ubiquitous sensing environments for humans. Through affective sensing of human emotions and behaviors, devices can respond accordingly to provide the users with a better human-computer interaction experience. While affective sensing provides electronic devices with a better understanding of humans, ubiquitous sensing provides humans with a better knowledge of their environments. Wireless sensor networks (WSNs) have been proposed for different ubiquitous sensing scenarios over the decades, and in-home monitoring is one of the successful examples that have been widely deployed. Algorithms designed to optimize such in-home sensor networks can also be mapped to other domains. In particular, the problem of optimizing coverage in directional sensor networks can be mapped to the problem of predicting the structure of proteins, an important challenge for bioinformatics research that is needed for effective drug therapy design. In this dissertation, we contribute algorithms to enable affective and ubiquitous sensing systems as well as algorithms to improve protein structure prediction.

Accurate acquisition and interpretation of human physical signals are two essential components for affective sensing. In the first part of this dissertation, we develop a speech-based emotion classification system, which uses several one-against-all support vector machines with a threshold-based fusion mechanism to combine the individual outputs. A thorough performance evaluation of this system is provided for different test scenarios, including classification using noisy speech samples and samples from real users. Results show that the system achieves a six-emotion decision-level correct classification rate of 80% for an acted dataset with clean speech. Applications for this proposed emotion sensing system range from behavior studies to context-aware electronics design.

Fundamental frequency (F_0) is one of the speech features used for emotion classification. However, noise is inevitably included during the speech signal's acquisition. We present a novel noise resilient F_0 detection algorithm named BaNa that combines the approaches of harmonic ratios and Cepstrum analysis. We test the performance of the proposed BaNa algorithm using real human speech samples corrupted by different types of noise. Results show that for almost all types of noise and signal-to-noise ratio values investigated, BaNa achieves the lowest Gross Pitch Error rate among all the classic and state-of-the-art algorithms.

In the second part of this dissertation, we study the aforementioned in-home monitoring problem, considering energy efficiency for both the monitoring and transmission processes. In particular, we evaluate the performance of different camera and motion sensor placement strategies, and formulate optimization problems to achieve the minimum energy consumption, longest network lifetime, or the lowest monetary cost. In the image transmission process, we present a energy efficient cross-layer image transmission model that allows the user to specify an image quality constraint by optimizing the lower layer parameters. Evaluations show that our scheme outperforms the default settings of the investigated commercial devices.

Inspired by the camera placement problem in WSNs, in the third part of this dissertation, we conduct an interdisciplinary study that combines the research fields of structural bioinformatics and communications to provide a novel solution to the problem of protein side chain prediction, which offers information critical to pharmaceutical research, such as structure-based drug discovery and rational drug design. We explore the application of sensor placement optimization strategies developed for WSNs applied to protein side chain prediction. The covered sensing areas in WSNs are represented by the three dimensional space occupied by atoms both on the backbone and on side chains of proteins. Rotamer preference and spatial density are taken into consideration when optimizing the atom placement in the three-dimensional space. Our preliminary benchmark results show that the proposed algorithm can effectively reduce the number of atom collisions compared to an initialized predicted structure.