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Machine learning approaches to understand the influence of urban environments on human's physiological response

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ABSTRACT

This research proposes a framework for signal processing and information fusion of spatial-temporal multi-sensor data pertaining to understanding patterns of humans physiological changes in an urban environment. The framework includes signal frequency unification, signal pairing, signal filtering, signal quantification, and data labeling. Furthermore, this paper contributes to human-environment interaction research, where a field study to understand the influence of environmental features such as varying sound level, illuminance, field-of-view, or environmental conditions on humans' perception was proposed. In the study, participants of various demographic backgrounds walked through an urban environment in Zürich, Switzerland while wearing physiological and environmental sensors. Apart from signal processing, four machine learning techniques, classification, fuzzy rule-based inference, feature selection, and clustering, were applied to discover relevant patterns and relationship between the participants' physiological responses and environmental conditions. The predictive models with high accuracies indicate that the change in the field-of-view corresponds to increased participant arousal. Among all features, the participants' physiological responses were primarily affected by the change in environmental conditions and field-of-view.

1. Introduction

Understanding influence of the environmental conditions on human perception is complex. Various environmental features, e.g., sound level, temperature, and illuminance affect our senses. Therefore, we adopted enhanced measurement and analysis techniques to define and measure what influences citizens in dynamic urban environments. The environmental features measured in this research include sound level, dust, temperature, humidity, illuminance and the field-of-view since they influence a person's sense that, in this research, was represented by the physiological state of a person, which was measured through electro-dermal activity (EDA). With the advent of technology, researchers explore the utility of sensor-based

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physiological data in real-world scenarios. Thus, researchers now have the means to explore how environmental features can affect individuals' physiological response-based perceptual quality and overall experience [23]. How to capture and define such a perceptual quality is an ongoing research topic in Cognitive Science and Behavioral Science [21,36].

This research presents a controlled study, conducted in Zürich, Switzerland, to acquire data on humans physiological responses and environmental conditions. In the study, 30 participants were asked to walk through an urban environment, while equipped with wearable sensor devices [15]. The study was designed to address the following research questions:

(a) Can we predict the physiological responses of participants based on particular environmental conditions?
(b) Can we infer the relationship between the physiological responses and the environmental conditions?
(c) What are the most significant environmental features affecting the participants' physiological responses?
(d) What are the patterns in the environmental conditions, for which the participants exhibit aroused and normal physiological responses?

The features of the data were recorded through devices and sensors at varying frequencies, which had both temporal and spatial properties. The features had a temporal property due to continuous recording, and the features had spatial characteristics because of the recording's association with the change in locations–global positioning system (GPS). Hence, in this research, we proposed a framework that performs signal preprocessing, signal filtering, signal quantifications, data fusion, and data labeling to answer the defined research questions.

Machine learning based techniques have been successfully applied for knowledge mining and pattern recognition in various real-world situations [32,39] since they are useful in identifying the underlying patterns within data [1,25]. Thus, we formulated the processed data such that four state-of-the-art machine learning techniques, classification, fuzzy rule-based inference, feature selection, and clustering, were applied for discovering patterns in the participants' physiological responses related to the urban environmental conditions.

The first step in this research was to assess the predictability of participants' perception (physiological responses) of the urban environment. Thus, a ten-fold cross-validation was performed on a reduced error-pruning tree (REP-Tree) classification model [29]. Following the classification approach, a fuzzy rule-based learning inferential model was built using fuzzy unordered rule induction algorithm (FURIA) [17] to investigate the relationship between the urban environmental features and the physiological response measures. Subsequently, the importance of various urban environmental features was analyzed by applying backward linear feature elimination filter (BFE) [22]. Furthermore, self-organizing map (SOM) [18] was applied to visualize the impact of urban environment features on participants' physiological responses. In the final step, a method for referencing GPS location (geo-location) to compute mean physiological response across all participants was developed. Since various methods were involved in data processing, additional graphics and multimedia can be found on the project website [12].

In summary, the following are three essential contributions of this research:

(a) a field study design for understanding human perception of the urban environment;
(b) a framework design comprising signal processing, signal quantification, and data fusion methods that invokes a novel of approach in physiological data quantification;
(c) a comprehensive analysis using four machine learning methods to discover the patterns which are crucial to our understanding of human perception in urban settings.

We organized this paper into seven Sections. Section 2 places this research in the context of literature and describes the experimental procedure. Section 3 describes signal preprocessing, multi-sensor information fusion, and machine learning techniques in detail. Section 4 is devoted to explaining the obtained results followed by a comprehensive discussion in Section 5. The challenges and opportunity of the research are presented in Section 6, and Section 7 concludes the findings of this research.

2. Human perception of the urban environment

2.1. Literature review

The process of measuring physiological data as an indicator of human perception is complex, particularly in real-world application since perception can be influenced by various factors [2]. However, physiological pattern recognition can derive significant evidence about human perception [27]. Similar to our research, Picard et al. [27] focused on physiological sensor data, specifically skin conductance, and they related high and low arousals as positive and negative biological reactions. Also, Picard et al. [27] focused on the collection and filtering of the physiological data to construct good quality data void of failure and corrupt signals. They formulated physiological data so that a k-nearest-neighbor classifier can predict human's physiological arousal-based perception. Krause et al. [19,20], on the other hand, used wearable device data, including physiology based sensor data (galvanic skin response), to identify user's state in terms of physiological and activity context using SOM based clustering. Specifically, they performed unsupervised learning to classify sensor data to determine the context from which the signals were generated.

In Wang et al. [38], pattern recognition and classification of physiological sensor signals were performed by first decomposing signals into its constituent features and by applying support vector machine to classify negative and positive